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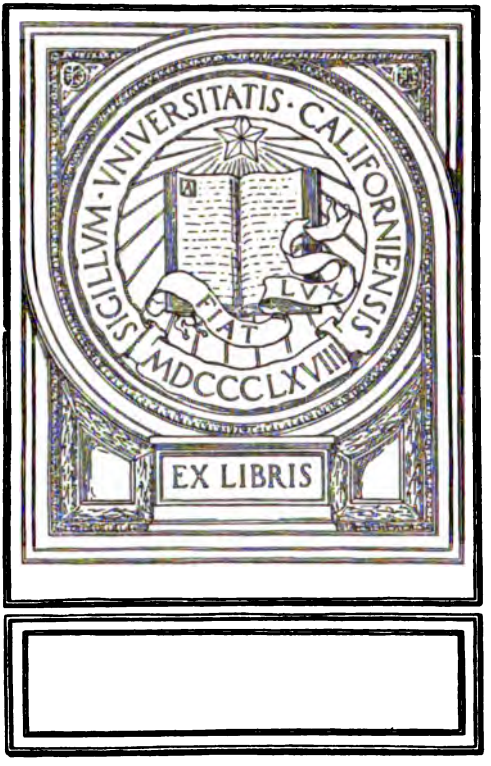
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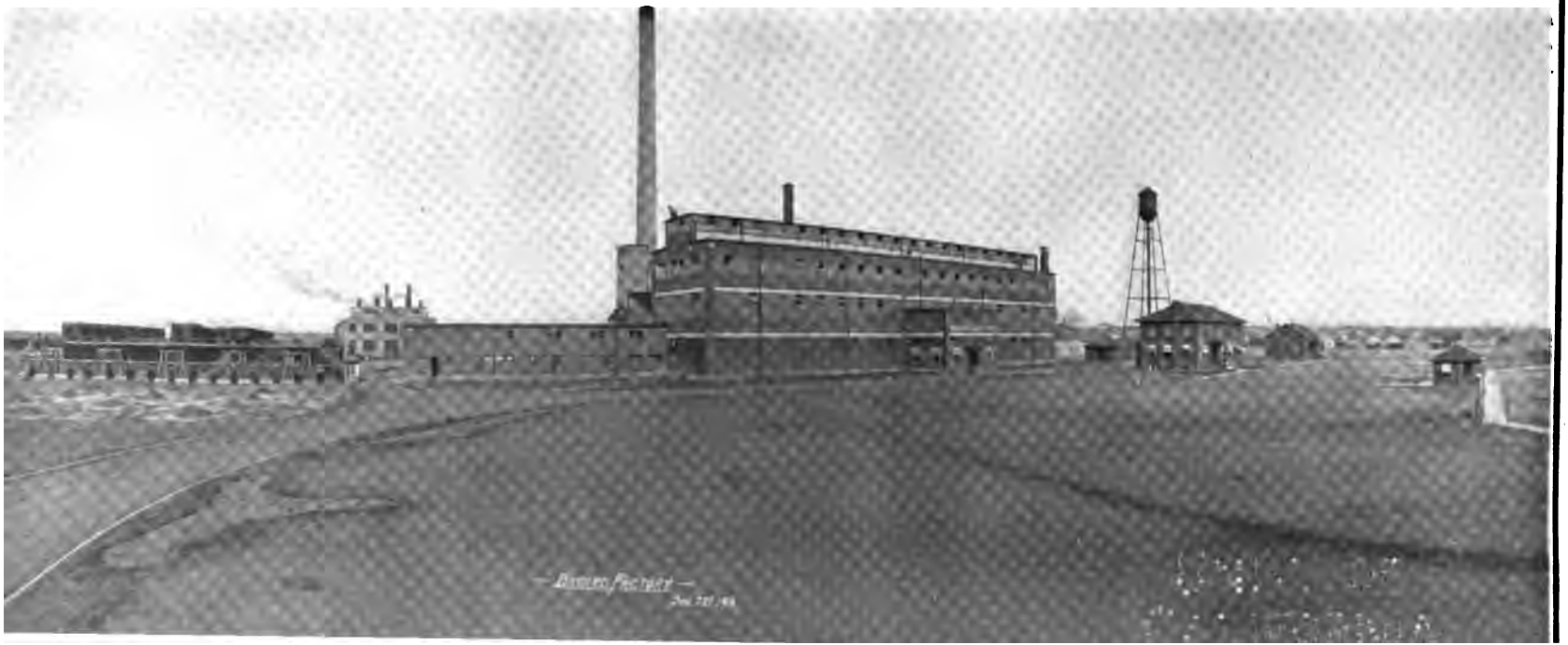

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TECHNOLOGY OF BEET SUGAR MANUFACTURE

A Textbook Describing the Theory and Practice of the Process of Manufacture of Beet Sugar.

UNIV. OF CALIFORNIA

By

THE GREAT WESTERN SUGAR COMPANY

FIRST EDITION

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PREFACE

The technology of beet sugar manufacture has made great advancement in the United States in the last twenty years. Operating methods have been changed and improved, and the study of a large amount of chemical and engineering data has resulted in the discovery of new principles, the practical application of which has thereby been made possible.

With the rapid expansion of the technical knowledge of the process of beet sugar manufacture, the Great Western Sugar Company has felt the need of a means of imparting to its employes a thorough knowledge of the operating technic and principles involved. To this end various members of the technical and operating staffs were asked to embody in a practical and not too technical treatise the methods and practice of the company. This treatise was used as a series of lectures in the vocational schools conducted for the benefit of new men entering the sugar industry and of older employes who felt the need of more information and a broader education in sugar technology.

The interest shown has been such that it has been deemed advisable to publish in book form the material prepared. The Great Western Sugar Company is offering "The Technology of Beet Sugar Manufacture" to its employes in the hope that an exchange of ideas will be an aid to a rapidly growing and very important industry in the United States.

As stated before, the book consists of a series of chapters on the important features of the technology of beet sugar manufacture. As the chapters have been written by different individuals, some variation in treatment and lack of unity of style is unavoidable, but this is undoubtedly more than compensated by the advantage of having had each lecture prepared by a man who is thoroughly familiar with and particularly interested in the given subject. Where the nature of the subject matter permits, each chapter is divided into two sections, "Section A" representing a descriptive treatise for the beginner, and "Section B" a more theoretical treatment for the advanced student.

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Mr. D. J. Roach is responsible for the inception of this work and for having prepared a large part of the text. Others who have assisted in the preparation and revision of the lectures are Messrs. N. L. Chatfield, O. M. Cummer, H. W. Dahlberg, V. I. Daniels, W. C. Graham, Bailey Hutchins, S. C. Mooney, S. J. Osborn and J. F. Rasmussen.

THE GREAT WESTERN SUGAR COMPANY.

Denver, Colorado, June 30, 1920.

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INTRODUCTION

The ordinary sugar of commerce, or cane sugar (sucrose) as it is called, has been known from ancient times, but it has not been used extensively in the human diet until comparatively modern times. At the beginning of the eighteenth century all sugar came from the cane plantations of the tropics and a large sugar trade had been built up between Europe and the tropical colonies.

The beet has been known in history about as long as cane, but it was not until 1590 that any one recorded the sweet properties of the beet, when Oliver de Serres prepared a syrup from beets and noted that "the juice yielded on boiling is similar to sugar syrup." Nothing more, however, came of this discovery until 1747 when Andreas Marggraf, a member of the Berlin Academy of Sciences, succeeded in preparing crystallized sugar from the beet by laboratory methods which are described as follows: "After having cut the beets into thin slices he dried them carefully and reduced them to a powder. On eight ounces of the beet thus pulverized, he poured six ounces of alcohol rectified as highly as he could obtain it and placed the mixture over a gentle fire in a sand bath. As soon as the liquid came to a boiling point he withdrew it from the fire and filtered it into a flagon, which he stoppered and left by itself. After some weeks he perceived that it had formed crystals, which presented all the physical and chemical characters of the crystals of sugar from cane. The alcohol which remained contained sugar in solution and also a resinous matter which he abstracted by evaporation."

No practical use was made of this discovery until 1799, when Achard, who had been a student of Marggraf, succeeded in presenting the king of Prussia with ten pounds of refined beet sugar, with a carefully written report on the methods used and on the economic importance of the industry. This resulted in the establishment of the first actual beet sugar factory in Silesia, which opened its initial campaign in April, 1802. During this time one hundred pounds of beets produced about three pounds of manufactured sugar. This factory and other early factories were successful only on account of the high sugar prices prevailing at that time.

The wars of Napoleon were in reality responsible for the establishment of the beet sugar industry on a paying basis. In 1806 Napoleon established a blockade against England, preventing any merchandise from England or her colonies being landed on the European continent, with the result that Europe was cut off from her chief source of sugar and a sugar shortage resulted. To overcome this shortage the French government offered a bounty on beet sugar, and in 1812 established six special beet sugar schools for select students, set aside large tracts of land, and compelled the peasant farmers to plant sugar beets. These various governmental acts, together with the high price of sugar during this time, advanced the beet sugar industry to such a point that forty factories were soon in operation in France and the industry had spread rapidly to Germany and Russia.

After the fall of Napoleon the European ports were again opened to the cheap sugar from the tropics, produced by slave labor, and the newly established beet sugar industry, because of the poor quality of the beets and the imperfect processes of manufacture, was unable to hold its own and only one factory survived the reconstruction period of the Napoleonic wars.

Up to this time no attempt had been made toward improving the quality of the beet, and the beets then used contained only 5 to 6 per cent sugar and were of low purity. In 1821 Pelouze, through researches in plant breeding, was able to increase the sugar content of the beets, and this, together with high sugar prices, caused the industry to make such rapid progress that by 1836 there were 436 sugar factories in operation. From 1836 to 1870 the growth of the industry in Europe and particularly in France, because of the attitude of legislation, was more or less spasmodic, but from 1870 to 1914, or the beginning of the World War, continual progress was made, and in 1914 the world's production of beet sugar was 9,051,767 tons as compared with a cane sugar production of 11,523,158 tons. Below is given a table showing the production of beet sugar by countries for the year 1914-15:

WORLD PRODUCTION OF BEET SUGAR

	1914-15 Short Tons
*United States	722,054
Germany	2,755,750
Russia	2,196,637
Austria-Hungary	1,766,252

France	333,954
Belgium	225,638
Netherlands	333,399
Sweden	169,644
Denmark	168,652
Spain	110,855
Italy	183,753
Bulgaria	25,573
Roumania	36,297
Servia	2,205
Greece	No Data
Switzerland	3,208
Canada	15,656
England	2,240
Australia	No Data
Manchuria	No Data
South America	No Data
Total	9,051,767

*Refined sugar; other countries given in terms of raw.

The development of the beet sugar industry in the United States has been more or less similar to that of Europe. Many years were required for this development and many failures resulted during the early years of the industry.

In 1838 the first factory in the United States was erected at Northampton, Massachusetts, by David Lee Child, but it was a failure and ceased to operate after 1840. Other factories were built by the Mormons at Salt Lake City in 1853, by the Gennett Brothers at Chatsworth, Illinois, in 1866; by Otto and Bavestell at Fond du Lac, Wisconsin, in 1868, and by E. H. Dyer at Alvarado, California, in 1870, but they were all failures as commercial ventures. In 1879 E. H. Dyer, after four complete financial failures and reorganizations, succeeded in putting the Alvarado plant on a paying basis, while in 1888 Claus Spreckels built a successful plant at Watsonville, California.

From this time on (1890) the growth has been in the main regular and constant, under a reasonably protective policy, until in 1915 seventy-nine factories, and in 1919 one hundred factories were operating in the United States.

The final success of the beet sugar industry of the world has been brought about by four main causes.

(1) The development of a beet containing a high percentage of sugar.

When Marggraf first made sugar from the beet its sugar con tent was very low, and the main reason why beet sugar could not compete with cane sugar after the fall of Napoleon was because of the low sugar content of the beet. This fact was finally recognized, and the botanists began their work of developing, by selection and plant breeding, a sugar beet of high sugar content. Such success crowned their efforts, after the invention of the polariscope, that the sugar beet of to-day contains three or four times as much sugar as the beets with which they started. This long line of plant breeding has brought the sugar beet to such a point that it is one of the most highly bred plants known, and to keep it up to its present standard constant care and selection in the production of beet seed must be observed.

(2) The introduction of improved farming methods, whereby the farmer is able to raise a large enough tonnage per acre to make beets a profitable crop. Another point in this connection which has greatly affected the growth of sugar beet culture in Europe is the realization among agriculturists that the introduction of beet growing into the farming rotation brings about better cultural methods and increases the crops following the beet crop.

(3) The perfection of manufacturing processes to a point where a high percentage of the sugar in the beet is extracted as crystallized sugar.

The manufacturing methods in the early factories were very crude, the losses were high, and the final yield of crystallized sugar was small. These methods were gradually improved, and the advances in the technical process of manufacture since the invention of the polariscope have meant much toward the establishment of the beet sugar industry over the world on a firm, financial foundation.

(4) The maintenance of a protective tariff on all imported sugar in most countries, or the placing of bounties on home grown beet sugar, which allowed the beet sugar industry to use the well paid labor of the temperate countries and yet compete with the very cheap labor of the tropics.

The manufacture of Beet Sugar is a technical process involving principles of Chemistry, Physics and Engineering. The methods of extracting the sugar, of purifying the juice, and of crystallizing out the sugar all depend upon the laws of chemistry and

physics, while the design and operation of the machinery necessary to perform the chemical operations require a knowledge of all phases of engineering. It is important that those engaged in the actual operation of the beet sugar factories should have some knowledge of the Technology of Beet Sugar Manufacture, and this work is compiled with the hope that it will provide some knowledge along technical lines to those who have had no opportunity in the past to secure this information.

The process used in the manufacture of beet sugar may be divided into five main parts: (1) The extraction of the sugar from the beets, (2) The purification of the extracted juice, (3) The evaporation of the juice to such a point that the sugar crystallizes out, (4) The separation of the crystals from the surrounding syrup by centrifugal force, and (5) The drying and packing of the finished product. To accomplish the purposes covered in each part several operations are needed, and in this treatise the working points and technology of each operation, or station, as it is called, is given. An attempt will be made to divide the subject matter for each operation into two parts so that at each factory it will be possible to hold two classes, one for the men who are more or less new to the work, and the other for those men who are familiar with the general operation of the factories and can do more advanced work.

All who are engaged in the Beet Sugar Industry should realize that it is one of the great food producing industries of the world and that its successful operation is important to the economics of the world. It is an industry that requires the best individual efforts of every one connected with it and offers great hope of expansion, and it is an industry with which any one may be proud to be connected.

CHAPTER NO. I

OUTLINE OF PROCESS AND EXPLANATION OF GENERAL TERMS

SECTION A

In every industry certain of the intermediate and end products, certain of the processes, and certain phases of the control of the processes acquire trade names which are unintelligible to one outside the industry or to a new man first entering the industry. The manufacture of beet sugar is no exception to this rule and a great many special terms or "trade names" are in such common use around beet sugar factories that it is almost impossible to write intelligently on Sugar Technology without using some of them.

An understanding of the trade names and of the terms used in the chemical control of a sugar factory is essential to anyone who is desirous of really obtaining a clear grasp of Sugar Technology, and before the details of the sugar making process are considered it seems advisable to devote one chapter to an explanation and definition of the various terms which are peculiar to beet sugar manufacture. It is likewise important that the person beginning the study of Sugar Technology should have a general idea of the process as a whole, and since an explanation of the trade names of the end and intermediate products can more readily be given in connection with a general explanation of the complete process, it is attempted in the following to give such an explanation, at the same time emphasizing by italics the various trade names of the intermediate products. In connection with the process explanation the student should follow Plate No. 1, which gives a diagrammatic relation of stations in sugar mills.

PROCESS EXPLANATION

The beets are flumed from the storage bins to the factory, washed thoroughly and elevated to the top of the factory, where they are weighed by automatic scales and delivered to the *"Beet Slicers."* In the slicers the beets are cut into thin slices, known as *"Cossettes,"* by knives revolving either in a horizontal plane, as in the *"Kilby"* slicer, or in a vertical plane, as in the French or *"Maguin"* slicer. The cossettes, after leaving the slicers, are placed in *"Cells,"* or vessels holding from two and one-half to seven tons of the cossettes, and water is circulated around them. Twelve or fourteen of these cells are connected as a *"Battery"* in such a manner that the water passes from one cell to another, begin-

ning at the cell that contains the most nearly exhausted cossettes and finally being drawn off as *"Diffusion Juice"* or *"Raw Juice"* from the cell in which the new cossettes are added. The exhausted cossettes, when free from all but a small percentage of sugar, are known as *"Pulp"* and this product is used as a cattle feed. The above, in brief, outlines the manner of extracting the sugar from the beet and the next step in the process consists in purifying the extracted juice, which may be outlined as follows: The diffusion or raw juice is sent through heaters to a station known as the *"First Carbonation,"* where *"Milk of Lime"* (which is usually lime slacked by a dilute sugar solution) or *"Saccharate Milk"* (described under "Steffen House") is added, and the mixture is then treated with *"Carbon Dioxide (CO_2)"* gas until most of the lime has been precipitated as calcium carbonate. After the carbonation has been completed to the point desired, the whole mixture is heated, either in the tanks or by being pumped through heaters, and is sent to the *"First Filter Presses"*, where the precipitated calcium carbonate and the impurities contained therein (called *"First Lime Cake"*) are removed. The purified juice from the first filter presses is known as *"First Press Juice"* and is pumped to *"Second Carbonation"*, where most of the remaining lime is precipitated by means of carbon dioxide gas. From second carbonation the juice is sent to the *"Second Filter Presses"*, where the precipitated calcium carbonate is removed as *"Second Lime Cake"* and the filtrate, known as *"Second Press Juice"*, is sent to *"Third Saturation"*, where it is treated with *"Sulphur Dioxide (SO_2)"* gas. After treatment with the sulphur dioxide gas and a further filtration through the *"Thin Juice Filters"* the juice, which is known as *"Third Press Juice"*, enters the *"Evaporators"*, where it is concentrated to a syrup containing about 50% sugar. The juice leaving the evaporators, called *"Evaporator Thick Juice"*, goes to the *"Blow-Ups"*, at which station melted sugar is mixed with it and the mixture is treated with sulphur dioxide gas, filtered through the *"Thick Juice Filters"* and becomes, after filtration, a syrup known as *"Blow-Up Thick Juice"*. The blow-up thick juice is drawn into the *"White Vacuum Pan"*, where it is concentrated to such a point that the sugar contained crystallizes out and the whole mass of crystals and liquor surrounding them is called *"White Massecuite"*. The white massecuite is placed in *"Centrifugals"*, where the crystals are retained on a screen and the syrup surrounding the crystals passes through and becomes known as *"High Green"*. Since some of the syrup remains on the crystals, it is necessary to wash them with a spray of hot water and the

syrup made by this washing is called *"High Wash"*. The washed crystals are dried by air in the *"Granulators"* and sacked as *"Granulated Sugar"*, while the high wash goes back to enter the next white pan and the high green is drawn into the *"Remelt* or *Raw Pan"* and concentrated to such a point that crystallization takes place. This mass of sugar crystals and the syrup surrounding them is known as *"Remelt Massecuite"* and the crystals are separated from the syrup by centrifgual force in the same manner as was done with the white massecuite. The syrup spun off is known as *"Low Green"*, the washed crystals are called *"Remelt Sugar"* and the syrup obtained during the washing is designated as *"Low Wash"*. The remelt sugar is melted up and added to the thick juice at the blow-ups, as stated before; the low wash goes back to the next remelt strike boiled, and the low green is sent out of the factory as *"Molasses"*, which is either used for cattle feed or sent to the *"Steffen Process"* for further sugar extraction. If the molasses is to be worked in the Steffen Process it is sent to the Steffen House and diluted to a solution known as *"Cooler Solution"* containing from 5 to 7 per cent sugar. The cooler solution is drawn into the *"Coolers"*, where finely divided lime is added which combines with sugar, forming an insoluble sugar lime compound. The material leaving the coolers is pumped to the *"Saccharate Presses"*, where the insoluble lime sugar compound, known as *"Saccharate Cake"*, is retained, while the non-sugars which are still in solution pass out with the *"Waste Water"* to the sewer or potash reservoir. The saccharate cake is diluted with a mixture of juice and wash water from the first carbonation presses forming *"Saccharate Milk"*, which is sent to first carbonation.

EXPLANATION OF CHEMICAL TERMS

In addition to the trade names of the intermediate products given above, other special terms enter into the general chemical control, and a knowledge and understanding of such terms as *"Dry Substance"*, *"Brix"*, *"Polarization"*, *"Purity"*, *"Alkalinity"*, etc., is essential to any one who desires to obtain a clear grasp of Sugar Technology.

Dry Substance.—The *"Dry Substance"* of a solution may be defined as the percentage of solid matter in the solution. Thus if 100 pounds of a sugar syrup, containing certain solids such as sugar, salt, etc., in solution, is evaporated to dryness and there

remains 50 pounds of solids or dry matter after the evaporation, the "Per Cent Dry Substance" of the original solution was 50.0. In other words, the "Per Cent Dry Substance" represents that percentage of the solution which will remain after all of the water has been evaporated.

Brix.—The word *"Brix"* is a term employed in sugar factory control which denotes the density or specific gravity of a sugar solution, but is used to represent the approximate "Dry Substance." If the solution is a *pure sugar solution*, such as a solution of granulated sugar dissolved in pure water, the *"Brix"* is the same as the "Per Cent Dry Substance." Thus if 100 pounds of pure sugar solution of 50° Brix is evaporated until all of the water is removed, there will remain 50 pounds of dry substance, or in this case the "Brix" of the solution is the same as the "Per Cent Dry Substance." However, the usual sugar solutions met with in sugar factories, such as raw juice, thin juice, thick juice, etc., are not pure sugar solutions, but contain other solids besides sugar in solution, and consequently the "Brix" represents only the *approximate* or *practical* "Per Cent Dry Substance of the Solution."

Polarization.—The word "Polarization" has, for practical purposes, the same meaning as "Per Cent Sugar," for it is by means of a process called "Polarization" that the chemist determines the "Per Cent Sugar" or "Sugar" in such products as "Cossettes", "Molasses Produced", "Molasses Worked", etc. A further discussion of "Polarization" will be given in the second part of this chapter.

Purity.—The term "Purity" is one of the most commonly used terms in connection with sugar factory work or control and a thorough understanding of its meaning is of importance to any one interested in the manufacturing process of beet sugar.

The "Purity" of a sugar solution may be defined as the percentage of the total solids or of the dry substance of the solution, which is sugar. If we have a sugar solution which upon evaporation will yield 100 pounds of dry substance and if this 100 pounds of dry substance contains 80 pounds of sugar, the purity of the solution will be 80. In other words, in this particular case *80% of the total solids or of the dry substance is sugar* and consequently the purity of the solution is 80. In arriving at the "Purity" of a sugar solution, the chemist determines the "Per Cent Sugar" and

the "Per Cent Dry Substance" of the solution and divides the "Per Cent Sugar" multiplied by 100, by the "Per Cent Dry Substance" and the result is the "Purity of the Solution". It is evident that the amount of water present does not influence the purity.

Non-Sugars.—As stated before, the usual juice or solution met with in a beet sugar factory contains, in solution, not only sugar but also other substances, such as salts, gums, etc., and these other substances are known as non-sugars. These non-sugars prevent the crytallization of the sugar from the juice and their removal, to as great an extent as possible, is one of the most important phases of beet sugar manufacture.

Alkalinity.—Solutions of different substances may be divided into three classes, acid, alkaline and neutral. Among the more common acids are sulphuric, hydrochloric (muriatic), nitric, acetic, etc., while lime, soda, potash, magnesia and ammonia are the common alkalies. A solution is said to be acid when it has the characteristics common to the above and other acids, while it is considered alkaline if it has properties in common with the alkalies. If a solution of alkali and a solution of acid are mixed in equivalent proportions, the resultant mixture will have the characteristics of neither an acid nor an alkali and will be what is called neutral. Acids and alkalies are distinguished from each other by means of substances known as "indicators" which have the faculty of changing color when the solution is changed from an acid to an alkaline condition or vice versa. Phenolphthalein, often incorrectly called "Phenol", is the common indicator used in beet sugar work and this indicator in an alkaline solution is pink, while in an acid solution it is colorless.

When a sugar solution is kept in an acid condition for any length of time there is danger that a portion of the sugar will be destroyed by a chemical change known as "inversion", and for this reason care must be exerted to see that sugar solutions are not allowed to become acid. At the same time the solution must not contain very much lime or it will be too viscous for good boiling work. The alkalinity in sugar house work is expressed as "Grams CaO (lime) per 100 cubic centimeters of juice".

SECTION B

Dry Substance and Brix.—In section A of this chapter "Per Cent Dry Substance" was defined as the "Percentage of solid matter in a solution", and it was stated that the "Brix" of a pure sugar solution was the same as the "Per Cent Dry Substance", while when dealing with impure sugar solutions the "Brix" represented only the approximate "Per Cent Dry Substance".

The determination of the "Brix" of a solution is very simple and is made by immersing a *Brix Hydrometer in the solution to be tested and reading off the "Brix" at that point where the surface of the liquid comes in contact with the scale of the hydrometer. (Note—The solution being tested must be of the temperature for which the hydrometer was standardized or a temperature correction applied.) On the other hand, the determination of the "Per Cent Dry Substance" is a rather slow and complicated matter and "Brix" instead of "Per Cent Dry Substance" is used for all practical control and for a good many calculations.

An understanding of the meaning of "Dry Substance" or "Brix" permits the making of many technical calculations regarding the quantity of water needed to be evaporated in order to raise a solution from one density to another, regarding how much juice a pump on any service must handle, etc., etc. As an example:

> How much water must be evaporated from 10,000 pounds of thin juice at 12° Brix to raise it to a thick juice at 65° Brix?

In concentrating a juice from one density to another only water is evaporated and there is the same quantity of dry substance in the thick juice as was originally present in the thin juice.

> Thus, the 10,000 pounds of thin juice at 12° Brix contains $10{,}000 \times \frac{12}{100} = 1200$ pounds of dry substance, and there must be contained in the thick juice at 65° Brix the same quantity of dry substance as in the thin juice, or 1200 pounds of dry substance, and since it is 65° Brix the weight of the thick juice must be $1200 \times \frac{100}{65} = 1846$ pounds, and the water evaporated is, 10,000 pounds (weight of thin juice) minus 1846 (weight of thick juice) = 8154 pounds.

*A Brix hydrometer is scaled to indicate the percentage of sugar in a pure sugar solution. It derives its name from one of the early investigators who determined the specific gravity values of sugar solutions on which the scale is based.

This calculation may be expressed by a formula as follows:

Let W = Weight of Thin Juice
A = Brix or % Dry Substance of Thin Juice
B = Brix or % Dry Substance of Thick Juice
X = Weight of water removed by evaporation

$$X = W - \frac{WA}{B}$$

In those cases where great accuracy is required the "Per Cent Dry Substance" should be used in the above formula instead of "Brix", but for practical control purposes the "Brix" is sufficiently accurate.

Polarization.—If a ray of light is passed through "Iceland Spar" it becomes what is known as *polarized and acquires the faculty of being rotated either to the left or right when passed through solutions of certain substances among which is sugar. This peculiar behavior is taken advantage of in the ordinary sugar polariscope and this instrument is so constructed that rotation of the plane of polarized light in passing through a solution can be measured, and by this measurement the quantity of the sugar in the solution determined. The method of making this determination may be described as follows:

A normal weight (26 grams) of the material to be tested is weighed out, transferred to a 100 cc. flask, and water and lead acetate added up to the 100 cc. mark. The lead acetate is used to remove coloring matter which would interfere with the accuracy of the reading. After thorough mixing the solution is filtered and the filtrate transferred to a 200 mm. polarization tube and read by means of the polariscope. The reading gives the "Polarization" or the apparent "Per Cent Sugar of the Solution." However, in

*Light consists of vibrations or wave motions at a right angle to the direction of the ray, in a medium called the ether which is assumed to pervade all space. A ray of ordinary light vibrates in all possible planes, but, if it is passed through a crystal of calcite (Iceland spar), it is resolved into two rays, each of which vibrates in only a single plane and in this condition is said to be "plane polarized" or simply "polarized." One of these two rays is eliminated by a suitable modification of the calcite crystal which is known as a Nicol prism. If light, polarized by passing through a Nicol prism, strikes another Nicol, it will pass through undiminished in intensity provided the screening effect of the second Nicol is parallel to that of the first; if the screening effect of the second Nicol is perpendicular to that of the first, no light passes. A polariscope in its simplest form consists of two Nicol prisms, between which the substance under investigation is placed. Sugar solutions rotate the plane of polarized light to the right; the extent of this rotation is dependent on the concentration and length of column of solution through which the light passes, and can be measured in a simple polariscope by rotating one of the Nicols until the rotation due to the sugar solution is exactly compensated. In the polariscope used for sugar analysis, known as a saccharimeter, the rotation caused by the sugar solution is measured by a movable quartz wedge, which is adjusted so that the thickness of quartz exactly neutralizes the rotation of the sugar solution. Attached to the quartz wedge is a scale which under standard conditions indicates directly the percentage of sugar in the solution.

the ordinary syrups as found in a beet sugar factory there are substances other than sugar which affect the polariscope in a similar manner to sugar and because of this the polarization as determined above represents only the *approximate* or *apparent* "Per Cent Sugar" of the solution. To determine the "Per Cent True Sugar" a second test known as the *"Clerget" or "Inversion"* test must be made which gives the "Per Cent True Sugar" or "Sugar by Inversion" of the solution. Since, unfortunately, the determination of the "True Sugar" of a solution is a complicated process, the ordinary polarization is used for practical control purposes.

Purity.—Purity has been defined as the percentage of the total solids or of the dry substance of a sugar solution, which is sugar. To determine the purity of a solution the chemist determines the "Per Cent Sugar" of the solution and divides it by the "Per Cent Dry Substance" and multiplies by 100. As an example, if we assume that we have a sugar solution containing 20% sugar and 23% dry substance the purity of the solution may be calculated by the following formula:

Let A = % Sugar of a sugar solution
B = % Dry Substance of a sugar solution
P = Purity of the solution

$$P = \frac{A}{B} \times 100 = \frac{20}{23} \times 100 = 87.0$$

As stated under the discussion of Dry Substance, there are two terms; one called "Per Cent Dry Substance", which represents the *true dry substance* of the solution, and the other called "Brix", which represents the *apparent* or *approximate* dry substance of the solution. In the same way the sugar content of the solution may be determined by direct polarization which gives the "Apparent Per Cent Sugar", or it may be determined by the Clerget or Inversion method which gives the "Per Cent True Sugar". Because of these apparent and true determinations of sugar and dry substance there have come into use two terms for expressing purity, "Apparent Purity" and "True Purity".

In calculating the "Apparent Purity" of a solution the "Polarization" is used as the per cent sugar and the "Brix" is used as the per cent dry substance, while in calculating the "True Purity", the "Sugar by Inversion" or "Per Cent True Sugar" and the true "Per Cent Dry Substance" are used.

The "Apparent Purity", because of its ease of determination, is used very extensively in practical sugar house control, while the "True Purity" is used for special control on some products such

as Saccharate Cake, Remelt Massecuite, Molasses Produced, etc., and for the more refined calculations. The thing to be remembered in connection with the discussion on "Purity" is that the fundamentals are the same whether "Apparent Purity" or "True Purity" is used, that is, the "Purity" of a solution is the percentage of the total solids or dry substance which is sugar.

Non-Sugars.—The "Non-Sugars" in a sugar solution may be defined as the percentage of the total solids or dry substance, which is *not* sugar. The "Non-Sugars" of a solution are determined by subtracting the purity from 100. Thus, in a sugar solution of 80 purity the non-sugars are 100 — 80 = 20, which means that of 100 parts of total solids in the solution 80 parts are sugar and 20 parts are non-sugars.

Non-sugars in beet sugar factory juices are made up of two classes: inorganic materials, such as salts of soda, potash, lime, etc., and organic materials, such as gums, organic acids, etc., and since their presence prevents the crystallization of sugar to such a point that every part of non-sugars in the final thick juice eventually takes with it one and one-half parts of sugar when it leaves as molasses, every effort is used in the manufacture of beet sugar to remove the non-sugars.

A thorough knowledge and understanding of the meaning of "Purity" and of "Non-Sugars" is important in the study of Sugar Technology, and such knowledge is needed in making a great many necessary technical calculations.

As an example of how these calculations may be used; it may be necessary to know how much sugar will be crystallized from a certain quantity of massecuite of definite purity and dry substance if the purity of the green syrup is known,

Let P = Purity of Massecuite or Higher Syrup = 90.0
K = Purity of Green Syrup or Lower Syrup = 80.0
W = Weight of Massecuite or Higher Syrup = 15,000 pounds
D = Per Cent Dry Substance of Massecuite = 90.0
L = Purity of Sugar Crystallized..... = 100.00
X = Weight of Sugar Crystallized

$$X = \frac{WD(P-K)}{L\ (L-K)} = \frac{15000 \times 90\ (90-80)}{100\ (20)} = 6750 \text{ pounds}$$

The above may be analyzed as follows: The weight of massecuite multiplied by the per cent dry substance, or W xD, is equal to the weight of the dry substance of the massecuite. Now, 100

pounds of dry substance of the massecuite, since it is of 90 purity, contains 90 pounds of sugar and 10 pounds of non-sugars, and since upon crystallization only sugar is crystallized out, the 10 pounds of non-sugars are still left in the green syrup. Thus, the 10 pounds of non-sugars in the green syrup are combined with enough sugar to make a syrup of 80 purity, or in 100 pounds of dry substance of green syrup, there will be 80 pounds of sugars and 20 pounds of non-sugars and the 10 pounds of non-sugars in a solution of 80 purity will give a green syrup dry substance of $\frac{10}{20} \times 100 = 50$ pounds. Since we started out with 100 pounds of massecuite dry substance and finally had left 50 pounds of dry substance in the green syrup, the sugar crystallized must be $100 - 50 = 50$ pounds, or the crystallization is 50%, and if the total weight of dry substance in the massecuite (WD) is multiplied by the per cent crystallization, the result will be the total weight of sugar crystallized.

Lime Salts.—The term "Lime Salts" is used to define certain combinations of calcium (lime) and organic acids which are found in most syrups in a beet sugar factory and which cause the syrups to become very viscous when concentrated and are often the cause of slow boiling pans. These organic salts may be formed from several sources; they may be formed by the plant acids in diffusion juice when the lime is added at carbonation or they may be formed because of faulty work at first carbonaiton or at the first presses. The failure to remove all of the lime by CO_2 in second carbonation means that some of it must be removed by means of sulphur dioxide in third saturation, and since the sulphites are more soluble in sugar solutions than are the carbonates, some lime sulphites may remain in solution and act as lime salts.

Some of the lime salts are broken up during the evaporation, forming scale on the evaporators, and this is particularly true of those formed by sulphitation of the juice, but most of them go through into the molasses. With normal beets and proper carbonating and heating of juices, the juices hardly ever contain enough lime salts to make the addition of soda advisable. At times, however, the lime salts accumulate to such an extent that soda must be added, but it should be used sparingly, for any soda added beyond that required to precipitate the lime salts acts as a molasses maker and takes its toll of sugar into the molasses, and even when soda is used in small amounts, the removal of lime salts is incomplete and additional non-sugar is thereby introduced into the juice.

CHAPTER NO. II

BEET STORAGE, BEET FLUMING, TRASH CATCHERS, ETC.

SECTION A

STORAGE OF BEETS

When a farmer delivers a load of beets at the dump, those beets cease to be the property of the farmer and immediately become the property of the Sugar Company. At this point the farmer's responsibility ceases; and it becomes the responsibility of the Sugar Company to see that each ton of beets delivered produces a maximum quantity of sugar.

It is beyond the scope of this treatise to enter into the details of the system of receiving and storing the beets, but since one of the great problems of the Company lies in the storage of beets and one of the great losses of sugar takes place in this storage, it is only proper that some mention should be made of this phase of the beet sugar industry. Owing to the climatic conditions of the districts in which we operate, such as shortness of growing season; which means that the beets, in order to mature, must be left in the ground as long as possible; and the earliness of frost, which makes it imperative that they must be dug before the ground freezes up; it is necessary to store a great quantity of beets each season. These two factors working together make the actual harvesting season of only four to six weeks duration and in fact probably 90 per cent of all beets are harvested between September 26th and November 10th. The slicing capacity of our factories is such that it normally requires from 90 to 100 days to slice the crop which is harvested in 50 to 60 days, with the consequent result that a very large part of the crop must be stored for quite a considerable time.

All sugar beets lose sugar during storage, but the amount of sugar lost depends to a large extent on the condition of the beet when put into storage and also on the method of storage. The healthy beet continues to respire, or breathe, and this breathing process uses up sugar; while with a rotten or unhealthy beet, the rotting action destroys the sugar. It is of course self-evident that even with the respiration the healthy beet loses much less sugar than does the rotten beet. Frozen beets, if kept in a frozen condition, are not seriously damaged, but if allowed to freeze hard and then to thaw, the beets will, upon thawing, decay very rapidly. A beet which is bruised in any way deteriorates much more rapidly

than an uninjured beet. Also experiments have shown that the higher the temperature of the beet while in storage, the higher is the sugar loss. This is true even in the case of healthy beets, for higher temperature seems to increase respiration and this is one of the reasons why the losses during the early part of the campaign, or on direct delivery beets, are so high.

Various methods of storage have been tried out, such as storing in large bins at the factory, siloing in the fields, and piling in large piles at the dumps. The storage of large quantities of beets at the factory in large storage bins has proven from the records available to be a method of storage which causes a considerable sugar loss, the greater part of which is probably due to the fact that these beets are handled very roughly; first, in passing over screens at the dump, and second, in being dumped from the car to the bins. In other words, the beets going into this storage are more or less bruised and this bruising makes them susceptible to deterioration. Another thing which has tended to increase the sugar loss in factory storage bins has been the fact that most of these bins are over beet flumes and very often the warm fluming water gets back into the flumes over which the beets are stored, with the result that those beets directly over the flumes are heated up and decay quite rapidly. Also, the temperature of the air and of the beets during this time is usually high, which makes for high sugar loss.

The storage of beets by siloing in the field makes for a low sugar loss when properly done, but since this siloing is often improperly done, it is questionable whether as an average any less sugar is lost by this method than by piling in large open piles.

After years of experimentation the method of storing the beets in large open piles at the dumps has become the most generally used method with our company and records over a period of years show a minimum sugar loss with this method of storing. One important point in connection with this procedure is to guard against piling frozen beets with good beets, for if this is done the natural heat of the pile will thaw the frozen beets out, they will begin decaying, and pockets of decay will soon be formed throughout the pile. Piled beets after being transferred to the factory storage bins deteriorate quite rapidly and it has become the practice, after the factory starts working piled beets, to keep as few beets in factory storage bins as possible.

After the above discussion on loss of sugar during storage, it may be interesting to investigate how great this loss is. Mr. Mendelson of the Agricultural Department has made some very extensive and important compilations along these lines and his deduc-

tions are that the loss of sugar per twenty-four hours, for each ton of beets in storage, is fairly constant for each different method of storage, and is as follows:

Type of Storage.	Pounds Sugar Lost Per Ton of Beets Per 24 Hours Storage.
Direct Delivery (Factory Storage)	1.80
Piled Beets	.66
Average	1.28

It is thus seen that for every day a ton of beets is kept in storage 1.28 pounds of sugar are lost, and when it is remembered that 1,500,000 to 2,000,000 tons of beets are stored each year for an average period of about 25 days, it can readily be appreciated that the loss is tremendous. In fact for the 1918-19 campaign, 9.39 per cent of the total sugar in the beets purchased, or 32 pounds of sugar per ton of beets, was lost between the time the beets left the farmer and entered the factory.

The greater part of this loss is unavoidable, but the factory man can be of some assistance, (first) by maintaining a maximum slicing capacity and thereby reducing the length of time that the beets are stored, (second) by watching the Booraem gates in the flumes to see that no water gets back into those flumes over which beets are stored, and (third) by taking care whenever handling beets, as in unloading cars, etc., to bruise them as little as possible.

FLUMING BEETS

In the early days of the beet sugar industry various methods, such as wagons, industrial cars, conveyors, etc., were used to transfer the beets from the storage bins to the factory. All of these methods were expensive and laborious, and the man who first conceived and carried out the idea of transporting beets by water (a Bohemian master mechanic) deserves a general vote of thanks from the industry.

The specific gravity of sugar beets is only a little greater than that of water and consequently when put into a moving stream of water they move rapidly along with the current. This makes the proposition of fluming beets a very feasible one and in fact this method is the one now universally used by all beet sugar factories.

The type of flume best suited for fluming a large capacity of beets with a minimum use of water has been the source of a good deal of experimentation and very few of our factories now use the flumes that were installed when the factory was built. This experimentation has led to the adoption of standard sections on both the

main flumes and the header flumes, which standard is now being used in all new installations. The standard cross-section for the main flume at a 1,000-ton house is 30″ depth and 18″ width, with a grade of one foot per 100 feet on the straight flume and 1¼ feet per 100 feet on curves, while the same section for an 1,800-ton house is 30″ depth and 24″ width with the same grades as the former. On the header flume there is an overflow which has become recognized as a very important feature both to prevent flooding of the flume when plugging occurs and also to help take the plug out by putting a stream of water at the toe of such plug.

The water used for fluming beets generally comes from the condenser seal tanks and is of a temperature of from 30 to 40° C. The bins over the flumes in some places have sloping sides commonly called "cones", and in others do not, and these "cones", when steep, help greatly in getting the beets into the flume, but they also take up storage space which is valuable. The saving in labor by having the "cones" has been balanced against the value of the extra storage space with the result that in a great many cases the "cones" have been removed.

As soon as the beet enters the water of the flume, sugar begins to diffuse from it and a certain quantity of sugar is lost during the transit of the beet from the storage bin to the factory. Experiments have been made along the line of determining this loss of sugar with beets of different states of preservation and in water of different temperatures, and below is a resumé of the results.

		SUGAR LOST Great Western Experiments		SUGAR LOST Claassen	
Condition of Beets.	Time in Water.	% on Beets.	Lbs. Per Ton.	% on Beets.	Lbs. Per Ton.
Fresh Beets	10 Min.	.04	.8	.03	.6
Frozen Beets	10 Min.	.13	2.6		
Rotten Beets	10 Min.	.19	3.8	.1 to .57	2.0 to 13.5
Wilted Beets	10 Min.	.04	.8		

In the above tests the beets were in the water for ten minutes, which various determinations have shown to be the average length of time that the beets remain in water from the time they enter the flume until they leave the washer.

Other tests in which the beets were left in the water for twenty minutes showed as follows:

	Sugar Lost % on Beets.	
Condition of Beets.	10 Min.	20 Min.
Fresh Beets	.04	.05
Frozen Beets	.13	.17
Rotten Beets	.19	.26
Wilted Beets	.04	.08

These tests show that the loss of sugar increases as the time that the beet is exposed to the water is lengthened, and this is especially true in the case of frozen or rotten beets, which means that every effort should be made to keep the beets in the water as short a time as possible. Very often at the factory the flumers continue poking the beets into the flume after they are whistled off by the washer man, with the result that the flume becomes full of beets, they move slowly when the factory starts taking them again, the beets are exposed to diffusion for a much longer time than they should be, and there is a loss of sugar which could have been prevented by careful supervision of the flumers.

From tests made to determine the effect that the temperature of the water has on the sugar loss it would seem that on fresh beets or frozen beets the temperature, within reasonable limits, has very little effect on the amount of sugar lost. However, on rotten beets an increase in temperature causes an increase in the sugar lost. In general this temperature is pretty well set by the temperature of the condenser seals and cannot be readily changed and also, since the fluming of the beets helps to loosen the dirt on them, warm water is necessary when fluming frozen beets. Bruised beets lose more sugar than do those which are uninjured.

In general we should recognize that there is a sugar loss during the transit of the beets in the flume amounting to from .04 to .19% on beets or at a 1,000-ton factory from 800 to 3,800 pounds of sugar are lost every day in the flume water. A portion of this sugar can be saved by endeavoring to bruise the beets as little as possible when putting them into flumes (by using poles instead of picks), and also by keeping the beets in the water as short a time as possible.

The fluming of beets may materially affect the slicing capacity of the factory and several general points of operation, if properly observed, will help the flumers in their work.

(1) All beet signals and whistles should be immediately obeyed.

(2) The beets should be fed into the flume as evenly as possible, for the slicing average depends to a large extent upon the evenness with which the beets are delivered to the factory. One of the best ways to accomplish this is to form a hole over the flume by moving a flume board back about 18 inches and then put the beets into the flume through this hole. Just enough beets should

be put into the flume at one time to supply the factory, for if too many beets get into the flume a plug may occur which will delay the factory and reduce the slicing average, and also by retarding the flow of water, allow dirt, sand, etc., to settle out. Also if too many beets are in the flume at one time, the stone catchers do not work efficiently.

(3) Picks should be used to as small an extent as possible and the beets should be moved into the flumes by means of wooden prod poles.

(4) Care must be taken to keep flume covers out of the flume since they may damage machinery in the factory.

(5) Any boards, rocks, iron or other foreign material found in the beets should be watched for and removed, as this material, if it gets into the slicers, will damage the knives and reduce the slicing average of the factory.

(6) The beets along the side of the flume should at all times be shoveled into the flume, so that no beets will remain which cannot be removed when working the adjacent flume.

(7) After a flume is finished, it should be flushed in order that no beets are left therein to decay.

(8) Attention should be given to the Booraem gates to make sure that they are tight on all flumes that are not being used, for if water accumulates under stored beets they will decay very rapidly.

TRASH CATCHERS

When the beets are delivered they generally have mixed with them a certain amount of trash, such as straw, beet leaves, alfalfa roots, etc., which material unless removed damages the slicer knives and thereby causes the production of poor cossettes. This trash is generally removed at several points, such as at the trash catchers, the grizzly bars between the washer and the elevator, the roller table and the picking table. The trash catchers remove the greater part of this trash and those generally in use may be divided into two classes, hand trash catchers and mechanical trash catchers. In the hand trash catchers several series of hooks are suspended in the flume, the trash is caught on these hooks and removed by hand, while the mechanical catchers have hooks, hung from an endless chain, which travel against the stream of the flume, gather the trash and are cleaned mechanically.

The grizzly bars between the washer and elevator, and at some plants the roller table, eliminate a great amount of trash and are generally beneficial, but at the same time they throw out a great many tailings and should be operated in connection with a tailing separator.

STONE CATCHERS

Two general types of stone catchers are in use, namely, the pulsating or "Franklin Type" and the Deepened Channel or "Dyer Type". In the pulsating type a pocket is made outside and under the flume and pistons keep the water in the flume pocket pulsating, the rocks being thrown down into the deepened portion where they are removed at intervals by opening a sluice gate. The Dyer type consists simply of a deepened section of the flume, a portion of which is grated off to take gravel and another portion left open. The gravel being heavier than water and smaller than the grating, passes by gravity into the gravel pockets while the rocks go into the section not grated. Gates on the side of the pockets are opened at intervals and the gravel and stones are removed. Both types work well where the sewer is sufficiently low that the sand and gravel can readily be washed away but do not work well when such is not the case. A thorough elimination of rocks and trash is essential to low knife consumption and the production of good cossettes, and the facilities available at each factory should be used to the utmost to accomplish this end.

BEET WASHER

The greater part of the dirt around the beets is removed in the flumes but there is still some work to be done in the washer. The beets should be freed from carrier water before entering the washer and then a very plentiful supply of clean water should be used, for not only does this help in removing gritty matter which might harm the knives but it also reduces the amount of bacteria, etc., clinging to the beet, thereby reducing the possible fermentation in the battery. Also stone and gravel catchers are built in the bottom of the washers, and to be effective they should be cleaned often and systematically. If this cleaning of the stone and rock pockets is done regularly much knife trouble can be prevented.

TAILING SEPARATORS

As stated above, at some plants, the grizzly bars or roller table between the washer and the elevator eliminate a great deal of trash,

but this trash carries with it large quantities of tailings. These tailings are valuable and if saved the saving amounts to from $5,000.00 to $10,000.00 per factory for each campaign. In the past some attempt has been made to hand-pick the tailings and attempt to recover them in this way, but in general this method is inefficient and expensive. Various attempts have been made to make machines which would separate the tailings and the trash mechanically, and these attempts have resulted in the perfection of two types of Tailing Separators.

The first of these separators was invented by Mr. Franklin of Fort Collins and is known as the Franklin Separator. In this separator the tailings and trash are thrown horizontally by means of a rotating propeller through several jets of water. The trash, being lighter than the tailings, is thrown down by the jet of water into a trash compartment, while the tailings pass through the jets of water and enter the tailing compartment, from which they are conducted to the beet elevator and thence to the slicers.

The second separator is known as the "Sailer" separator and it also depends on the difference between the specific gravity of the tailings and the trash, but the separation is made by a flotation process. The mixture of tailings and trash is conducted into a compartment full of water in which the water enters at the bottom and overflows at the top. The water entering the bottom keeps the water in the compartment agitated; the tailings being heavier than water sink to the bottom, while the trash, which is lighter than water, floats off with the overflow.

Tailing separators will probably soon be in the equipment of every factory and when installed every effort should be made to save a maximum amount of the tailings. Where mechanical separators are not provided an attempt should be made to make this separation by hand and save as many tailings as possible.

PROBLEMS

(1) A factory cuts 1,200 tons of beets a day and all of these beets were in water an average of ten minutes. How many pounds of sugar were lost if the rate of diffusion was such that .05% sugar diffused in ten minutes?

(2) A factory cuts 55,000 tons of direct delivery beets and 65,000 tons of piled beets. The direct delivery beets were in storage an average of ten days and the piled beets were in storage an average of 32 days. How many pounds of sugar were lost according to Mr. Mendelson's figures given on Page 18.

(3) Given the formula:—

$$X = \frac{A + B}{C} + \frac{C(A - B)}{B}$$

$A = 96$

$B = 32$

$C = 16$

Substitute and find the value of X.

(4) A beet knife for the slicer costs approximately 75 cents and it takes 48 knives per slicer. A picking table man went to sleep and let a piece of iron through which ruined 1/3 of the knives in the slicer. This man was working for 50 cents per hour. How many hours of work did he throw away by his carelessness?

(5) If each piece of iron that the picking table man picks out saves 16 knives, how many pieces of iron must he find during the season to pay his wages, for a campaign of 100 days, if he receives 50 cents per hour?

SECTION B

As stated in Section A of this chapter, the storage of beets is one of the most important phases of our work and the loss of sugar during this storage is one of the largest losses that occurs in the sugar industry.

Mr. Mendelson has made some very important investigations along this line and in this section an abstract of these investigations and the conclusions drawn are given.

EXPECTED DIFFERENCE BETWEEN BEETS BOUGHT AND SLICED

If the weight and sugar content of the beets delivered at the sheds were determined with absolute accuracy, and if there were no loss occurring during the storage in sheds, if further the weight and sugar content of the beets sliced were also determined with absolute accuracy, the following circumstances should cause a difference between the two determinations.

The net weight of the beets delivered is determined dry. Beets will absorb a certain amount of water while in the flumes and washers. Also they are weighed in the factory with a certain amount of water adhering to the skin. This will tend towards increasing the weight of the beets sliced as compared with that of the beets delivered.

During the fluming and washing of the beets some tails are separated from the beets and do not get into the factory scales.

This will tend toward decreasing the weight of the beets sliced as compared with that of the beets delivered. The water absorbed by and adhering to the beets will lower the percentage of sugar in the beets sliced as compared with that in the beets delivered.

A small amount of sugar diffuses from the beets into the flume water, while additional sugar is contained in the tailings. The amount of sugar in the beets sliced would then be less to this extent than that in the beets delivered, even if there was no loss in storage and if the two determinations were accurate and comparable.

The increase in weight due to absorption of water and adhering moisture is commonly assumed in Europe to be about 3 per cent, which is probably a little higher than in reality.

The amount of tailings lost is hard to estimate and undoubtedly depends largely on the number of straggly side roots of the beets. The maximum of tailings recovered at any of our factories was .35 per cent of the beets sliced. It is safe to estimate that the amount of tailings lost is at least as much.

Therefore, the net effect of these factors on the weight and sugar content of the beets delivered as compared with that of the beets sliced, if there were no loss in storage, should be:

First: That the weight of the beets sliced is slightly higher than that of the beets delivered at the sheds.

Second: That the percentage of sugar in the beets sliced is slightly lower than that delivered at the sheds.

Third: That the amount of sugar in the beets sliced is slightly less than that delivered at the sheds.

However, our method of determining the net weight of the beets delivered consists in making deduction from the gross weight not only for dirt, but also for a certain amount of top.

This top tare was determined separately, in 1915, on our piled beets and varied at the different factories from 1.10% in the case of Greeley to 1.94% in the case of Ft. Collins.

Therefore, if the amount of dirt tare was correctly taken, and such beets were sliced without loss in storage, the weight of the beets sliced should be higher than that delivered at the sheds, not only by the amount of water absorbed and adhering, but by the amount of top tare; minus, of course, the loss in tailings. At present a minimum amount of top tare is taken to prevent farmers from leaving too much valuable beet with the tops in the fields.

FUNDAMENTAL FACTS OF THE BEHAVIOR OF BEETS IN STORAGE

The behavior of sugar beets in storage has been investigated in great detail, and the fundamental facts have been ascertained with great accuracy. Most of this work has been done at the experimental station of the sugar manufacturers of Austria-Hungary in Vienna.

The conclusions are as follows:

Beets may, or may not, lose in weight during storage, depending on the condition of the beets going into storage, and the moisture of the storage medium. Wilted beets stored under moist conditions, either in moist sand or moist air, will increase in weight, while crisp beets stored in dry air or dry soil will lose in weight.

Beets cannot be stored under any conditions without loss of sugar. A topped beet is a living organism. The sugar in the beet is used up during the life of the beet for respiration purposes and, provided there is a sufficient supply of oxygen from the air, the sugar is transformed mainly into carbonic acid and water. A few other products are formed, the nature of which has not been fully ascertained; all of which, however, seem to exert a deteriorating influence on the crystallizing power of the juices obtained from such beets.

The normal respiration losses are largely exceeded when the beets contain fungi capable of development in storage, as these fungi live partly on the tissue and partly on the juice of the beet.

If there is not sufficient access of oxygen, the process taking place in the beets is of a different nature. Sugar is then not oxidized into the final products of combustion (carbonic acid and water), but into intermediate ones. The most noticeable of these is alcohol, which by further oxidation is transformed into acetic acid (vinegar).

A lack of oxygen in the air surrounding beets in storage is often brought about in our sheds. Very high and wide masses of beets are naturally not ventilated sufficiently to remove the products of normal respiration. Therefore, the air surrounding these beets gradually becomes richer in carbonic acid and poorer in oxygen.

Locally this may take place if loose dirt or trash accumulates between beets, stopping a free circulation of air.

This process is named "intramolecular respiration" in contrast with the normal respiration described above. Beets subjected

very long to this process die, so to speak, from smothering, as any living being would die in an atmosphere without sufficient oxygen.

While the sugar consumed directly per day by the process of intramolecular respiration is less than that by normal respiration, the process has a very damaging effect on the beets. Taking the oxygen necessary for the combustion of sugar from the tissue of the beets, naturally breaks down this tissue into undesirable, soluble non-sugars, which enter the juices. It also makes the beets more liable to attack by fungi living on the dead tissue of the beet.

Frozen beets also are subject to intramolecular respiration. The spaces between the cells constituting the tissue of the beets are filled with ice crystals, barring the access of the oxygen to the inside of the beet; thawing out breaks down the cellular structure entirely. While sugar itself is not destroyed to an abnormal extent in the early stages of this development, the dead tissue is in a favorable condition for the subsequent rot. Also the composition of the beet has been affected unfavorably for the extraction process in the factory.

We have at present no simple means, such as chemical analysis, to show the deterioration of beets as far as their working quality in the factory is concerned, although the practical factory operator and the sugar boiler notice such deterioration very quickly. Ultimately, the net per cent granulated extracted from such beets shows the deterioration better than any other figure.

The normal respiration loss has been found to be in proportion to the length of storage as well as to the temperature at which the beets are stored, although this loss varies with the quality of the beets. Beets grown with a large surplus of nitrogen, and therefore containing a large amount of protein, lose more sugar than beets grown with a normal supply of food. Since beets absorb from the soil the largest part of their nitrogen in the first two-thirds of the growing period, this means that immature beets as a whole will be inclined to lose more sugar in storage than fully matured beets. With the present highly bred beet varieties, beets with less than 16 per cent sugar cannot be considered mature. Measured by this standard we do not always obtain matured beets.

It, therefore, may be taken for granted that these normal sugar losses will be the greater the longer the beets are stored and the higher the temperature at which they are stored. Decrease in these losses, therefore, can be brought about only by diminishing the length of storage, or by storing at a lower temperature.

METHODS OF STORAGE

We employ three different methods of storage: Storage in sheds, meaning rather high piles; storage in piles, meaning rather low piles subject to quick changes in the temperature of the surrounding air; and storage in earth covered silos.

The comparative merits of these different methods of storage, with reference to the losses of sugar alone, can be gauged by their influence on the temperature at which the beets will be kept during storage.

The process of oxidizing the sugar in the beets, called respiration, produces heat and moisture. If piles are so big and so high that the naturally generated heat cannot be removed by the introduction of cool air, the beets naturally maintain a higher temperature and therefore will be subject to a higher sugar loss per day than beets kept in low piles to which cold air has free access.

Keeping beets in earth covered silos will produce low sugar losses only if beets are kept cooler than under other conditions. The earth covering will undoubtedly prevent the absorption of heat by the beets from the sun. On the other hand, if the earth cover is sufficient to prevent the escape of heated air surrounding the beets, the temperature of the beets and therefore the losses per day will ultimately be quite high.

Covering small beet piles with earth, therefore, is not a universal prevention of sugar losses. The fact that the silo experiments conducted at different factories in different years have given such irregular results as to sugar losses, show nothing else than that the beets in those silos, for some reason or other, were kept at different temperatures.

Making temperature observations of beets in storage ought to be a fairly exact method of ascertaining what is happening in piles. So far, we have overlooked this point except for some occasional observations by Mr. Maxson.

Real Sugar Losses.—Real Sugar losses of beets in storage proceed from the time the beets are received until they are sliced, and are generally in proportion to the length of storage and to the temperature at which they are stored.

Very careful and complete laboratory experiments at the Vienna experimental station gave the following results:

Sugar losses per day per 100,000:

At 32° F. from 2.3 - 5.2
At 41° F. from 10.4 - 18.7
At 50° F. from 23.0 - 29.6

The losses at each temperature took place at a uniform rate per hour, no matter how long the test lasted.

Dr. Claassen in Germany made experiments in piles of 15,000 tons, about 6 feet high, and found these losses:

	Loss	Stored At
In 1893 —	11.7	41° F.
In 1894 —	9.1	39° F.

It is interesting to note that the losses found in the laboratory experiments are confirmed by the losses found in big piles.

Beets were siloed last year in a potato cellar near Eaton at presumably 40 to 50 degrees Fahrenheit, with the following result:

Loss per day of storage per 100,000 pounds beets, 17.0 pounds sugar.

This figure again falls within the limits found by the Vienna experiments for the temperature of 41° F.

Silo experiments were conducted at nine of our factories in 1913. The beets were stored from 31 to 83 days. The loss of sugar per day per 100,000 pounds beets varied from 5.1 to 52.4 pounds. However, of the nine tests reported, seven showed losses of 10.8 to 5.1, and only Ft. Collins with 32.6, and Loveland with 52.4 pounds, exceeded this.

The temperatures at which these beets were kept are not known. The range of the losses per day in seven of the nine tests falls within the limits given in the Vienna experiments for the maximum loss at 32° F., and the minimum at 41° F.

In other words, the Vienna figures seem to furnish a standard by which to gauge sugar losses as far as these losses are brought about by the normal behavior of normal beets at varying temperatures.

Calculating the losses for the average of the Great Western Colorado factories on the same basis, we find:

Sugar losses, per day of storage, per 100,000:

In 1910..... 77.8
In 1911..... 76.3
In 1912.....103.4
In 1913..... 45.6
In 1914..... 51.1
In 1915..... 44.1

Our losses are greater in every case than the maximum found in Vienna for storage at 50° and are far greater than found by Dr. Claassen in piles 6 feet high.

Last campaign we were able to separate the beets sliced from direct delivery, and those sliced from piled beets, with sufficient accuracy to ascertain all the data, including the length of storage for the different classes of beets.

Sugar losses per day per 100,000 were:

For direct delivery beets....90.5
For piled beets 32.9

The losses from the piled beets are a little more than the maximum given in the Vienna experiments and about three times as high as the losses in piles in Dr. Claassen's experiments.

The higher losses of the direct delivery beets per day, as compared with those of piled beets, cannot be explained by a larger error in the determination of the net weight and sugar content of this class, but must be caused by their being stored at a higher temperature than that employed in the Vienna experiments.

The sheds are usually piled full during the warmest part of the delivery season. The height of the piles in the sheds usually exceeds that of the outside piles. The masses are larger and not subject to the same ventilation. The average temperature of many days exceeds 50° F.

A few temperature measurements available for the "high lines" at Longmont made by Mr. Maxson during October 11-22, 1914, show that, while the daily average temperature in the high lines ten feet from the top fluctuated, at three different points the following figures were obtained:

North Bin (1) 51.0 - 66.2° — Average 54.7° F.
Bin next to 1 (2) 53.0 - 68.6° — Average 58.7° F.
300 ft. from 1 (3) 58.5 - 68.0° — Average 64.2° F.

These observations confirm those of Dr. Claassen, that the *average* temperature in piles is higher than the average of the surrounding air.

It is interesting to note that in the north outside bin the temperature dropped suddenly during a spell of cool northwest wind.

That the losses are proportionate to the length of storage for the whole crop can be seen from a study of the averages for individual factories for the three campaigns, 1912, 1913 and 1914.

Factory	Average Days Storage for the Whole Crop.	Loss of Sugar Per 100 Sugar Bought. Total.	Per Day of Storage.	Loss of Sugar Per 100,000 Beets Bought. Per Day of Storage.
Longmont	27.2	10.16	.37	58.8
Loveland	22.5	9.22	.41	64.9
Ft. Collins	22.4	9.06	.41	68.3
Eaton	14.6	6.06	.42	65.1
Greeley	14.5	5.95	.41	65.5
Windsor	12.3	5.31	.43	67.5
Sterling	10.8	4.38	.41	63.0
Brush	8.6	4.21	.49	73.2
Ft. Morgan	10.0	4.17	.42	64.0

Although the total losses at the different factories vary considerably to the extent that the maximum at Longmont is 2½ times as high as the minimum loss at Ft. Morgan, these losses calculated per day of storage vary very little with the exception of Longmont and Brush. In the majority of cases the losses per 100 sugar bought, per day of storage, vary from .41 to .43, and the same losses per 100,000 lbs. beets, per day of storage, vary from 63.0 lbs. to 68.3 lbs.

This makes the following conclusions possible:

1st. Comparing the widely differing average sugar losses at the different factories for the three years 1912, 1913 and 1914, the length of storage of the whole crop on hand is the decisive factor.

2nd. That whatever other influences bring about these losses, as calculated by the difference between beets bought and beets sliced, they do not differ materially at the different factories, at least as far as the averages of the three years 1912, 1913 and 1914 are concerned.

3rd. While presumably the average temperature at which the beets were kept, at the different factories, did not vary much, the temperatures at which beets are kept in sheds and piles vary considerably, with a resulting variation in loss per day of storage.

LENGTH OF STORAGE

Beets which cannot be sliced immediately after receipt must be stored.

The excess of daily delivery over the daily slicing determines the quantity of beets to be stored.

The excess accumulated at the end of the receiving period and the time it takes to slice this excess, determines the average length of time that the whole crop has to be stored.

The minimum length of storage is determined by the quantity of beets it is considered necessary to have available in sheds, in transit, or in piles before the slicing begins.

If six days' slicing is accumulated before the campaign begins, if the crop is delivered in 60 days at an even rate per day, and if the crop is sliced in 60 days, the average storage for the whole crop will be 6 days. However, this average will naturally be composed of some beets with less and some with more storage. Some beets may be dumped into the flumes directly from the cars, others may be kept in the sheds considerably longer, but of whatever extremes the average is composed, this average will remain the same as long as fundamental conditions remain the same; namely, in this case:

(1) Starting with beets enough for 6 days' slicing on hand.
(2) Delivering the crop in 60 days.
(3) Delivering the crop at an even rate for 60 days.
(4) Slicing it in 60 days.

For instance, the fact that some beets were stored in piles instead of in sheds would not altar the average storage days.

If one of these fundamental conditions is changed, the average storage is changed. If the crop is sliced as fast as delivered in any case, the average days' storage is determined only by the number of days' slicing on hand.

Therefore, one means of diminishing the average length of storage is to start with less beets on hand than is customary. This discussion has nothing to do with whether other considerations make this advisable or not.

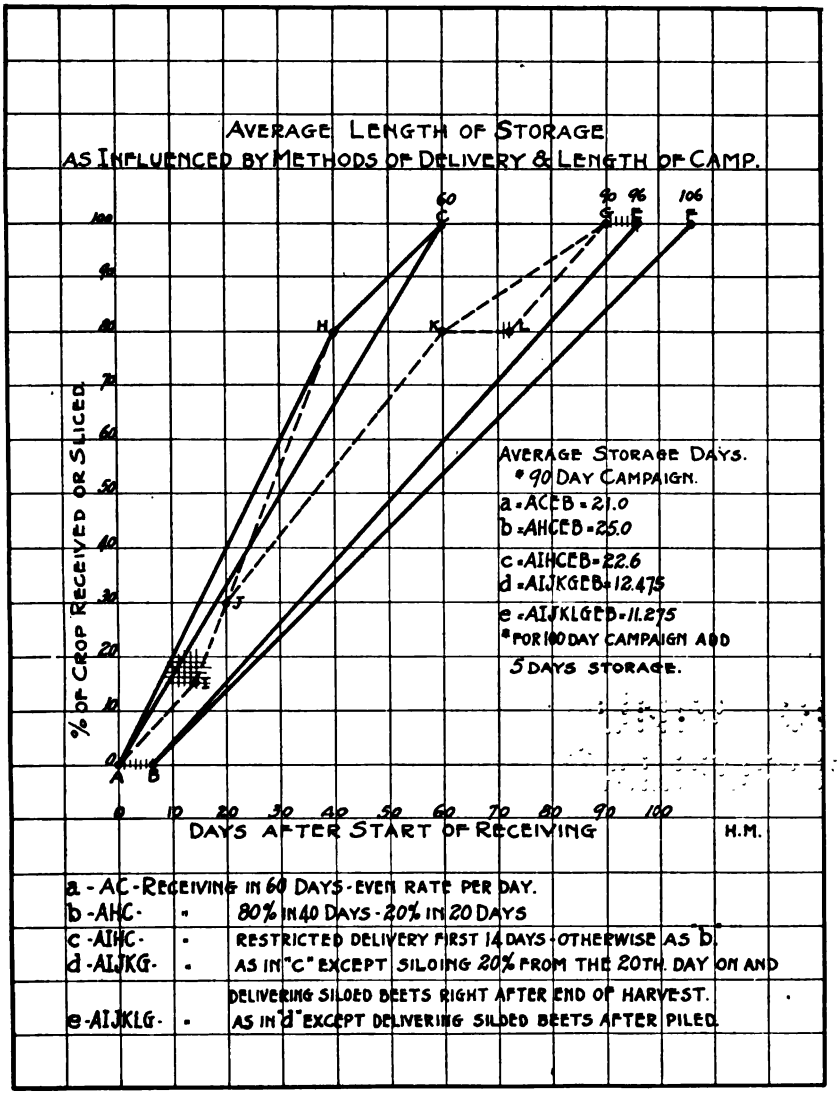
However, it appears from the experience of many campaigns that the amount of beets accumulated before starting has provided a very ample factor of safety.

The influence of the various factors affecting the length of storage can best be discussed in connection with the included graphical representation (Plate No. 2).

The vertical lines are numbered consecutively and represent days elapsing since the beginning of the delivery. The horizontal lines represent per cent of the total crop either received or sliced.

If we mark, every day on its proper date line, the per cent of the total crop received up to this day, and connect these points by lines, we obtain what might be termed the receiving line.

Plate No. 2.


AVERAGE LENGTH OF STORAGE
AS INFLUENCED BY METHODS OF DELIVERY & LENGTH OF CAMP.
% OF CROP RECEIVED OR SLICED
DAYS AFTER START OF RECEIVING
H.M.
AVERAGE STORAGE DAYS.
* 90 DAY CAMPAIGN.
a = ACEB = 21.0
b = AHCEB = 25.0
c = AIHCEB = 22.6
d = AIJKGEB = 12.475
e = AIJKLGEB = 11.275
* FOR 100 DAY CAMPAIGN ADD 5 DAYS STORAGE.
a - AC - RECEIVING IN 60 DAYS - EVEN RATE PER DAY.
b - AHC - " 80% IN 40 DAYS - 20% IN 20 DAYS
c - AIHC - " RESTRICTED DELIVERY FIRST 14 DAYS - OTHERWISE AS b.
d - AIJKG - " AS IN "c" EXCEPT SILOING 20% FROM THE 20TH. DAY ON AND
e - AIJKLG - " DELIVERING SILOED BEETS RIGHT AFTER END OF HARVEST. AS IN "d" EXCEPT DELIVERING SILOED BEETS AFTER PILED.

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If we mark the same points for the per cent of the total crop sliced up to date and connect them, we obtain what might be termed the slicing line.

If, for instance, the crop is received in 60 days at an even rate per day, the receiving line will form a straight line connecting the zero point and the 60 point on the horizontal 100 line (Line A C). Similarly if we start slicing 6 days after beginning to receive the crop, slice the crop at an even rate per day, finish slicing 90 days after starting the campaign, or the 96th day after beginning to receive, the receiving line will connect point 6 on the horizontal zero line with point 96 on the horizontal 100 line (Line B E).

The trapezoid included by the lines A C and B E and the parts of the two horizontals between them, pictures graphically the storage area.

The average length of storage is then the average length of the horizontal lines between the lines A C and B E.

Geometrically the average storage days are the side of a rectangle with the same area as the trapezoid A C B E and the height of 100. In this case $\frac{6 + (96 - 60)}{2} \times 100$, divided by $100 = 21$.

Expressed in words, the average storage days for the whole crop in a campaign where delivery and slicing proceeds at an even rate per day are equal to one-half the number of days' slicing on hand at the beginning of the campaign plus one-half the number of days elapsing between the last day of delivery and the last slicing day.

INFLUENCE OF METHODS OF DELIVERY ON STORAGE DAYS REQUIRED

As a matter of fact, the delivery does not proceed at an even rate per day. It usually proceeds faster in the first 40 days of the delivery season than in the last 20 days. If, for instance, 80 per cent of the crop is received at an even rate up to the 40th day and the rest in the next 20 days, the receiving line would be represented by the broken line A H C. This obviously adds to the storage area the triangle A H C, and is equal to 4 days in this case. Based on the calculation mentioned above, this would be equivalent to 5 x \$40,000 = \$200,000 on a 1,500,000-ton crop and 5c sugar. In other words, speeding up delivery increases the storage required at our hands and the sugar loss caused thereby. On the other

hand, if we succeed in restricting delivery, as we can during the first two weeks of the campaign, so that we receive beets only as fast as we slice them during this time, we diminish the storage required.

In the case where 80 per cent of the crop is delivered by the 40th day, if we restrict delivery up to the 14th day so that about 15 per cent of the crop is delivered up to that time, the storage days would be reduced from 25 days' unrestricted delivery to 22.6. The delivery line would then be represented by A I H C.

One method of restricting delivery during the *whole* delivery season is to have the farmer silo his beets and deliver them after the harvest season is over. If, for instance, in the last mentioned case, with restricted delivery, we should require the siloing of 20 per cent of the beets and we assume that beets will be siloed beginning with the 20th day of delivery, we would then receive 80 per cent of the crop only by the end of the harvesting season, or by the 60th day after starting delivery.

If, then, the siloed beets are gradually delivered so that they are all in 6 days before the end of the campaign, the delivery line would then be represented by the line A I J K G. The area J H C G K would then represent the saving in storage by siloing. In this case with a 90-day campaign 12.475 storage days would be required by the whole crop as compared with 22.6 days without siloing.

If the siloed beets are received after the piled beets have been sliced, we would receive no beets after the harvesting season for 12 days, and then the siloed beets could be taken as fast as they are sliced, always keeping 6 days' supply on hand, meaning that all the siloed beets are received 6 days before the campaign closes.

The delivery line would be represented by A I J K L G. The resulting average storage would be 11.275 days when receiving siloed beets after the piled beets are in, as compared with 12.475 days when receiving siloed beets right after the harvesting season, and with 22.6 days without siloing.

It is obvious from these considerations that the benefits resulting from siloing are not so much the saving of storage on the 20 per cent siloed, but from the diminished storage of the 50 per cent of the crop delivered during the siloing season.

On a 90-day campaign this saving of storage is 11.3 — 10.1 — 1.2 days. The additional saving by receiving siloed beets after the piled beets are in is therefore only 1.2 days, or about 10 per cent of the total saving possible.

The saving of storage days is the same for campaigns of any length, provided the method and length of delivery is the same.

How close these theoretical figures are to results actually accomplished can be seen from the following:

Average for campaigns, 1912, 1913 and 1914:

Sterling, 106.4 slicing days 10.8 storage days.
Loveland, 107.6 slicing days 22.5 storage days.

Sterling siloed 20 per cent of the crop.

Loveland siloed almost nothing.

Sugar losses per 100 sugar bought:
Sterling 4.38 per cent.
Loveland 9.22 per cent.

Loss per day of storage:
Sterling 0.41.
Loveland 0.41.

Saving of storage days by siloing 20 per cent.....11.7 days.

Saving of loss of sugar.....4.74 per cent.

All the previous cases are based on a 60-day delivery season, which is about the average if the harvesting season begins October 1st. The end of the harvesting season is naturally determined mainly by weather conditions, which cannot be foreseen in the beginning. If we want to prolongate the harvesting and delivery season, we can do it only by starting harvesting earlier. For 10 days earlier start under otherwise similar methods, we diminish the storage area by a triangle with the base of 10 and the height of 100, equivalent to a decrease of 5 storage days, or 0.5 day saving per day earlier start. This on the basis of the calculation previously mentioned is $20,000 on a 1,500,000-ton crop and 5c sugar.

The objection to early starting, besides the practical difficulty of getting the farmer to do it, is that beets have not reached the maximum development either as to sugar per cent or sugar per acre. However, the area harvested below its maximum development is only a small part of the whole.

Comparing, for instance, a start by September 20th and October 1st, and assuming the end of the harvesting season by November 30th, the maximum area likely to be harvested by October 1st, when starting September 20th, would be one-seventh of the whole, but probably not that much.

If we assume that the one-seventh of the area harvested early produces only 90 per cent of the average harvested after October

1st, the total crop of sugar would be only 98.6 per cent of what the late harvest would average. This loss of 1.4 per cent may be compared with the saving effected in storage of five days and in sugar losses, on the basis of the 1915-1916 campaign, of 0.262 per day equals 1.31. This seems to be no net saving on paper, but the diminution in the crop by early harvesting is presumably overestimated, while the saving in sugar losses is presumably conservative and based on the lowest losses per day we ever obtained.

Of course financially an important consideration is that we might pay the fiat rate for beets considerably below the standard per cent sugar.

It is often important for deciding certain policies to know how much sugar is lost in the beet storage, and to determine this loss the above principles are made use of in the following formula:

Let A = Tons beets in storage.
B = Per Cent sugar in beets.
C = Average number of storage days.
D = Tons sugar lost in storage.
D = .004 x A x B x C.

To find the value of the sugar thus lost it is only necessary to multiply the "Tons sugar lost" by the value or selling price.

The determination of the average number of storage days sometimes offers difficulties, but, as previously stated, may be derived as follows: "The average storage days for a whole campaign where delivery and slicing proceeds at an even rate per day are equal to one-half the number of days slicing on hand at the beginning of the campaign plus one-half the number of days elapsing between the last day of delivery and the last slicing day." This can be expressed in a formula:

Let M = Number of days slicing on hand at beginning of campaign.
N = Number of days of beet delivery.
O = Number of days between beginning of delivery and end of slicing.
P = Average number of storage days.

Then: $P = \frac{M + O - N}{2}$

PROBLEMS

(6) (a) If the tonnage of beets for a factory is 208,000 tons, the delivery begins October 1st and ends November 25th, the slicing begins October 7th and ends December 30th, what will be the average number of storage days? (b) How many tons of sugar will be lost in storage if the beets contain 16 per cent sugar?

(7) (a) If in the above example the delivery begins October 1st and ends on November 25th and the slicing begins on October 5th and ends on December 28th, what will be the average number of storage days? (b) How many tons of sugar will be lost in storage?

CHAPTER NO. III

KNIFE STATION AND DIFFUSION BATTERY

SECTION A

After the beets are washed they are elevated to the upper floor of the factory and pass through the Automatic Scales, where they are weighed. At most factories there is a slat conveyor, or picking table, which carries the beets from the elevator to the scales and where a great amount of trash can be removed by hand picking. It is highly important that the beets be as clean and free from trash as possible and therefore that the hand picking at the slat conveyor be carefully and completely done.

All of the beets entering the factory are weighed in the automatic scales; these weights are used in computing the amount of sugar entering the house and it is essential that the scales be as nearly accurate as possible. A registering mechanism records the number of thousand pound dumps and the number of pounds of overweight. On account of the size of the beets it is impossible to weigh them out in exactly 1,000-pound lots, so each dump is made to weigh a little over that amount and this overweight is recorded. Several times each shift the automatic scales are checked against an ordinary scale and these checks are used every day to correct the weights recorded by the automatic scales.

The man operating the automatic beet scales should realize the importance of his work and observe the following points of operation:

(1) The registering device should be read once an hour and the reading recorded, since it is important that the foremen know how many tons of beets are being sliced.

(2) Occasionally the scales will dump with but few beets in the basket, that is, make a "false dump", and a record of these false dumps should be made so that the laboratory may make correction for them in computing the weight of beets. If this is not done the factory will be charged with more beets than have really been sliced. A false dump may be defined as a scale dump where the basket is less than one-half full of beets.

(3) The automatic scales will not operate properly unless they are thoroughly clean, and the keeping of the scales clean is one of the most important duties of the operator.

(4) In most factories the scale man notifies the washer man when to start and when to stop the beets, and by the proper handling of these signals he may assist materially toward keeping a steady flow of beets into the factory. Another important point is that the hoppers should not be filled beyond a point where the scales can dump freely, because, when this happens, several pounds of beets may be taken back in the basket and reweighed, and the weight of beets recorded thereby rendered inaccurate.

From the scales the beets pass to the slicers, where they are cut by revolving knives into thin slices known as *"Cossettes"*. Two general types of slicers are used; one, in which the knives rotate in a horizontal plane, is known in our Company as the "Kilby" slicer, while the other, in which the knives rotate in a vertical plane, is known as the French or "Maguin" slicer.

The importance of the knife station work cannot be overemphasized, for upon the quality of the cossettes depends to a large extent the slicing capacity of the factory, the quantity of sugar lost in the pulp, the amount of impurities eliminated in the battery, the amount of battery draft, and the quantity of sugar finally sacked. Good cossettes may be defined as "V" shaped slices of beets, clean cut, smooth and long, without square slabs or fine material. Plate No. 3 shows a sketch of a beet slicer knife, the manner in which the knives are set in the block, the slice cut from the beet, and the cross-section of a perfect chip. New knives, after the first 1/4 inch or less of the blade is used up, are too thick to make a long smooth slice and, to overcome this difficulty, the excess metal is removed from the knife by routing. This routing must be carefully done since, if the knife is left too thick, the chips are broken off too short on account of being bent too much when they leave the knife, while if routed too thin, the knife will break out when filed. After being routed the edge is put on the knife by filing and this must be carefully done, as any dull or rough spots on the knife will rupture a great many of the plant cells and will give a ragged cossette, which works badly in the battery. At the same time the bevel on the cutting edge should be such that it will not dull easily and still be great enough to cut a smooth slice, for if filed too thin the edge will turn back as soon as the beets strike it and when this happens the knife is dull. Poor chips are often caused by dull spots or "shiners" in the corners of the knives and these dull places not only bruise the chips themselves, but collect grass roots, trash, etc., in the slicers and cause mushy cossettes. (Note—At some factories the knives are filed

before being routed, which has the advantage of giving the filer plenty of stock to work on, while at other factories the knife is first routed and then filed. The latter method works for economy in files and reduces the time needed to file the knife.)

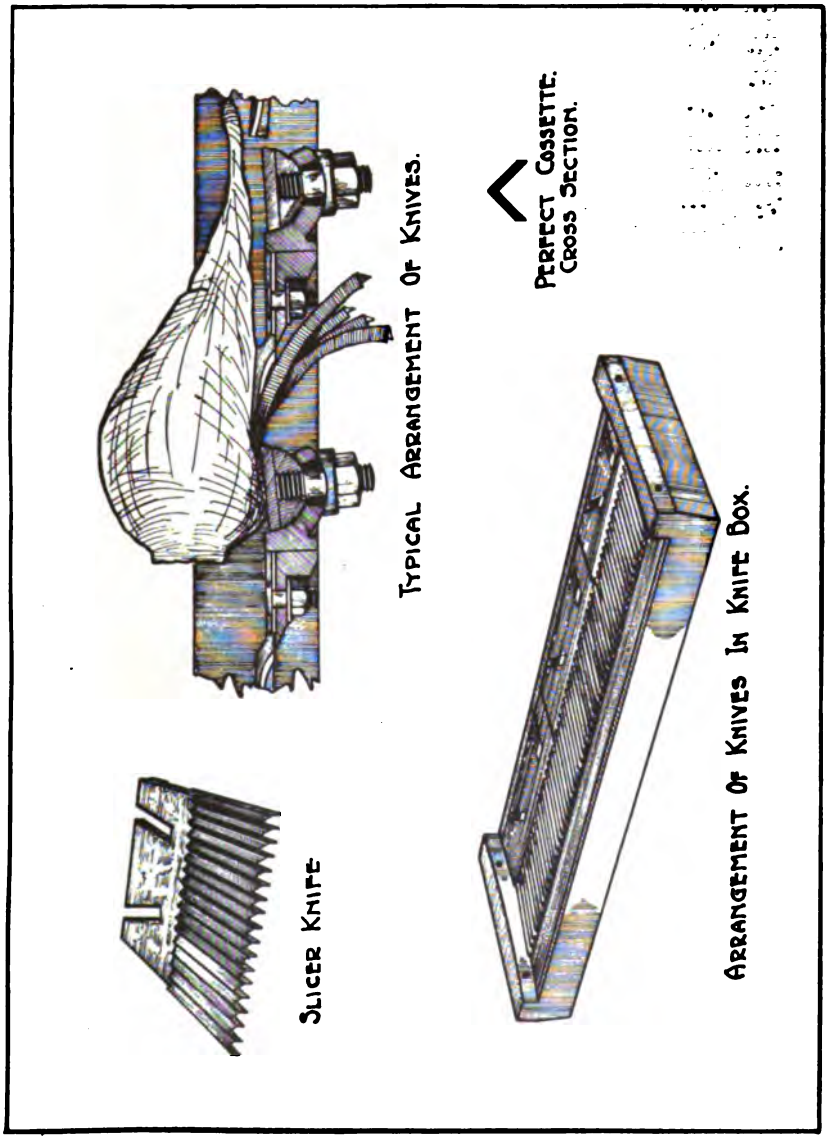
The sharpened knives are then set in the knife blocks. In order that "V" shaped slices be made, it is necessary that the corrugations of the knives follow each other in the slicers. To accomplish this the blocks are carefully made to fit the slicers and a tram used for setting the knives exactly right in the blocks. At some factories corrugated bars are used in front of the knives to guide the beets and cause them to strike the knives properly. The thickness of the cossettes is determined by the height of the points of the knife above the rocker bar in front of the blade. The cutting edge should be back from the rocker bar far enough so that the knife will not become clogged up with trash and still close enough so that slabs and pieces of beets cannot get through. Accurate gauges are used for setting up the knives and the work should be carefully done. The best dimensions for setting will vary with the nature of the beets and must be learned by experience.

After the knives are placed in the slicers they should be kept clean and free from trash and replaced as soon as dull. The knives are sometimes kept clean by rotating brushes, which knock the trash off the blades and cause it to fall through the openings between the knives and the rocker bars, while in other cases steam is used for the same purpose. An important point in connection with the brushes is to make sure that the rotation of the brush is faster than the travel of the slicer disc.

When the knife blocks are placed in the slicer, the slot in the disc should be well cleaned, for otherwise the knives in one block will not track with the knives in the next block and all the good work done in carefully setting the knives may be nullified. If the knives do not track, square slabs instead of clean cut "V" shaped cossettes will be cut. The knife work so fundamentally affects the battery work that in any smoothly running factory there must be complete co-operation between the two stations.

The beets, after being sliced into cossettes, are delivered to the battery, which consists of a series of "cells", or vessels, ranging from 150 to 420 cubic feet capacity, where water is circulated around them. These cells are so connected together that the water may be circulated from one cell to another, beginning at the cell that contains the most nearly exhausted cossettes and finally being

Plate No. 3.


SLICER KNIFE
TYPICAL ARRANGEMENT OF KNIVES.
PERFECT COSSETTE.
CROSS SECTION.
ARRANGEMENT OF KNIVES IN KNIFE BOX.

drawn off as diffusion juice from the cell in which the new cossettes are added. The exhausted cossettes are known as pulp.

In the manufacture of sugar the diffusion process serves a double purpose; first, the removal of the sugar from the beets, and second, the separation of the sugar from certain soluble non-sugars which also exist in the beets. To understand the action which takes place in the battery it is necessary to conceive the natural phenomenon of "Osmosis" and to know something of the structure of the beet. If a solution of sugar is placed in a bladder suspended in pure water, after a time it will be found that some of the sugar has passed through the membrane and that the water outside of the bladder is as rich in sugar as that within. This action is called Osmosis and the wall through which the material passes is called the Osmotic membrane. A great number of substances, especially those capable of assuming a crystalline form, behave in the same way as sugar. The beet structure is made up of a series of elongated cells containing a solution of sugar and certain non-sugars. The tissue of these cells consists mainly of pectic substances and cellulose, forming an Osmotic membrane.

The diffusion process takes advantage of the principle of Osmosis. As the water circulates around the cossettes in the diffusion battery it gradually becomes richer by gathering sugar which has passed through the cell walls, finally leaving the battery in the form of diffusion juice. To remove the sugar from the beets with the least amount of water, the battery is so operated that in reality the beets pass through in one direction and the water in another, or as we say in counter-current. A detailed description of the diffusion battery is not necessary; it is simply a series of "cells" or "diffusers" connected together so that the juice may circulate from one to another, with means of applying the water pressure to any cell and of drawing the diffusion juice off from any cell. Means are provided for heating the liquid between cells; in some cases this is done by the injection of live steam, but more often by means of heaters, or "calorisators", heated by vapor, which are more desirable on account of ease of control and better heat economy, as will be explained in another lecture. Just how the juice circulates through the battery can be best shown by the diagrams and explanations given on Plate No. 4.

For good battery work it is important to secure the *maximum sugar extraction,* which means low pulp, and at the same time take with this sugar as *few impurities as possible;* or in other words, to secure a maximum increase in purity between the cossettes and

diffusion juice. To accomplish these things it is necessary to have good cossettes (which means clean cut, "V" shaped beet slices containing a minimum of fine material, ragged edged slices and square slices), a fast circulation, good battery supply water, and just enough heat to render easy the passage of sugar through the walls of the plant cells. The heat should be carried on the head end of the battery with the pulp end at as low a temperature as possible. All of this should be accomplished with as low draft as possible.

As a general rule, if the sugar in the pulp becomes too high it is necessary either to raise the heat or to increase the draft. Both of these things are disadvantageous, the one because it tends to increase the impurities in the diffusion juice, and the other because it increases the amount of water to be evaporated in the evaporators; and in practical operation it becomes necessary to get the proper balance between these different factors.

The battery circulation becomes slow at times, and this may be caused by the fact that the beets are of such quality that the cossettes next to the screens are unable to sustain the weight of the beets above them and the openings in the screens thereby become plugged. The use of chains suspended within the cells, to lighten the load on the screens, is often of assistance. While the chains interfere with the uniform distribution of the cossettes and thereby to some extent cause uneven extraction and increased draft, their employment is quite general to obtain increased slicing capacity without the installation of additional equipment. In many cases the plugging of the screens may be caused by using too much heat on the battery and may be remedied by decreasing the temperature.

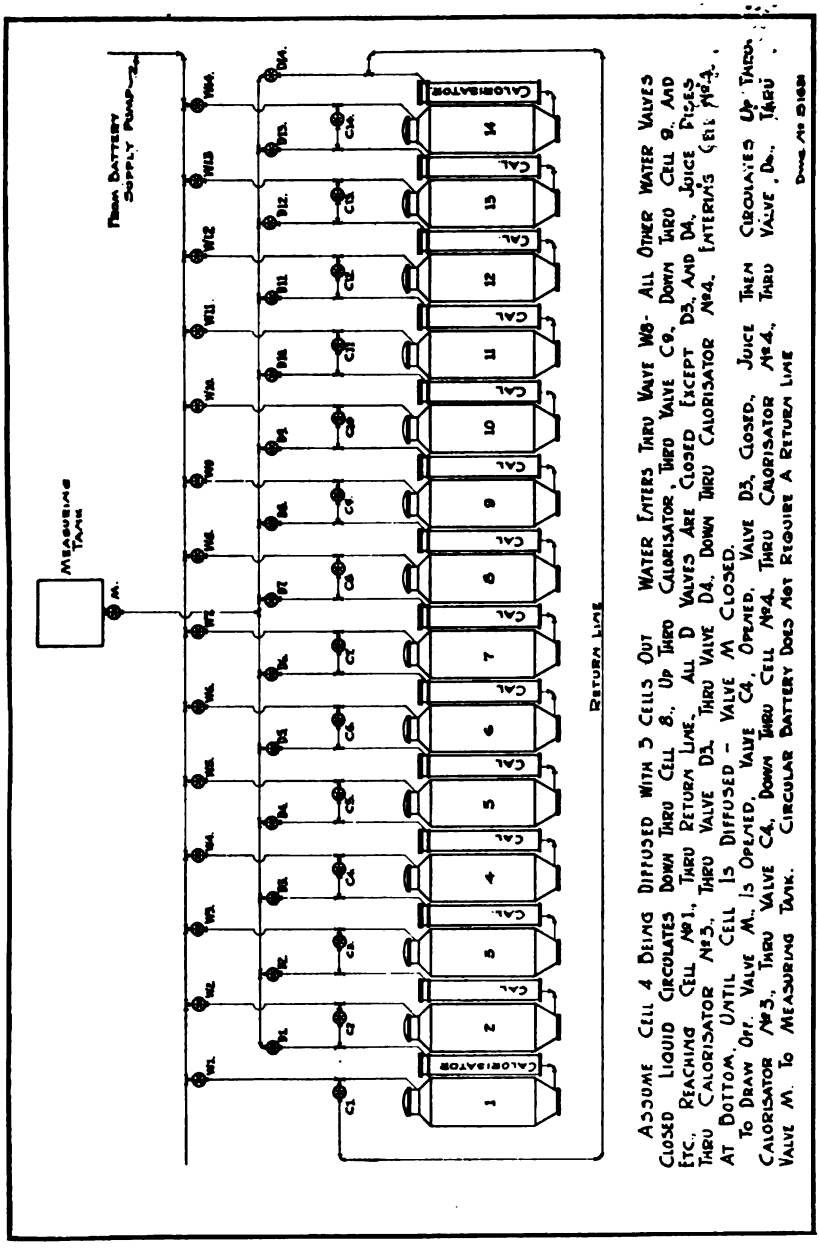
Several practical points of operation should be watched, among which may be mentioned:

(1) A complete co-operation between the knife station and the battery must exist, and the battery man *should watch the cossettes at all times,* for any decided change in the character of the cossettes necessitates a change in the method of operating the battery.

(2) The cells should be well cleaned when dumped and the chains frequently inspected to see that they are in good condition. Also attention must be paid to the filling of the cell, for a well filled cell usually means a lower draft, even circulation, and increased slicing capacity.

(3) An even temperature and accurate draw must be maintained, for unevenness in this feature will mean uneven pulp and

Plate No. 4.



ASSUME CELL 4 BEING DIFFUSED WITH 3 CELLS OUT CLOSED. LIQUID CIRCULATES DOWN THRU CELL 8., UP THRU CALORISATOR, THRU VALVE C9, DOWN THRU CELL 9, AND ETC., REACHING CELL №1., THRU RETURN LINE. ALL D VALVES ARE CLOSED EXCEPT D3, AND D4, JUICE PIPES THRU CALORISATOR №3. THRU VALVE D3. THRU VALVE D4, DOWN THRU CALORISATOR №4. INTERMIS (CELL №4.) AT BOTTOM. UNTIL CELL IS DIFFUSED – VALVE M CLOSED.
TO DRAW OFF. VALVE M., IS OPENED. VALVE C4, OPENED. VALVE D3, CLOSED. JUICE THEN CIRCULATES UP THRU CALORISATOR №3., THRU VALVE C4, DOWN THRU CELL №4. THRU CALORISATOR №4., THRU VALVE D4, THRU VALVE M. TO MEASURING TANK. CIRCULAR BATTERY DOES NOT REQUIRE A RETURN LINE
DWG. № 8188

poor elimination. It is also important that the air be thoroughly exhausted when the cell is diffused, since if not done it may slow up the circulation and increase the sugar in the pulp.

(4) The quality of the battery supply water is of importance in connection with the elimination of impurities, and where the double supply system is in use, the valves should be so handled that there is the least possible mixture of the pure and impure water.

(5) The operation of the battery materially affects the efficiency of the factory, both as to slicing capacity and daily sugar production. The decrease of .03 per cent in the sugar content of the pulp means an increase of 6 bags per day in the sugar production of a *1,200-ton factory, and 12 bags per day in a *2,400-ton factory. In the same way, the increase of one point in the purity of the diffusion juice means an increased daily production of 63 bags at a 1,200-ton factory and 126 bags at a 2,400-ton factory.

QUESTIONS FOR DISCUSSION

(1) On what principle does the diffusion process depend?

(2) How do ragged and dirty cossettes affect the battery operation?

(3) If the evaporators were holding the house and the pulp were high, how would you go about reducing the pulp?

(4) If the evaporators were not holding the house and the pulp were high how would you go about reducing the pulp?

(5) Why is it important to use the double battery supply at some factories?

(6) If the circulation slowed up, what would you do to speed it up?

SECTION B

As stated before, to understand the action which takes place in the battery it is necessary to conceive the natural phenomenon of "Osmosis" and to know something of the structure of the beet. If a solution of sugar is placed in a bladder suspended in pure water, after a time it will be found that some of the sugar has passed through the membrane and that the water outside of the

*Factories with slicing capacity of 1,200 and 2,400 tons per day respectively.

bladder is as rich in sugar as that within. This action is called Osmosis and the wall through which the material passes is called the Osmotic membrane. A great number of substances, especially those capable of assuming a crystalline form, behave in the same way as sugar. The beet structure is made up of a series of elongated cells containing a solution of sugar and certain non-sugars. The tissue of these cells consists mainly of pectic substances and cellulose, forming an Osmotic membrane.

The diffusion process takes advantage of the principle of Osmosis. As the water circulates around the cossettes in the diffusion battery, it gradually becomes richer by gathering sugar which has passed through the cell walls, finally leaving the battery in the form of diffusion juice.

To simplify matters, we will discuss first the principles governing the removal of sugar from the battery and later those governing the separation of the sugar from the non-sugars. As was stated before, the greater part of the sugar is removed from the cossettes by passing through the wall of the plant cells; however, in slicing beets, a great many plant cells are ruptured and of course the solution contained in these, impurities and all, goes immediately into the juice. This should be a very small part of the total, so for this discussion we will assume that all of the sugar is removed by Osmosis.

The rate of sugar transference, and by this is meant the efficiency of the diffusion battery, depends upon several conditions which are under control:

(1) The area of cell wall exposed.

(2) The ease with which the sugar passes through the wall.

(3) The difference in density between the juice within the plant cell and that without.

The amount of sugar which will pass into the juice in a given time is directly proportional to the area of cell wall exposed to the action of the juice. The thinner the slices the greater will be the area, provided they have sufficient stiffness to prevent them from matting together. The "V" shaped cossette has been found to have the greatest area and at the same time to retain sufficient rigidity so that openings will be formed for the liquid to circulate through. Square or flat chips decrease both the area and the stiffness and therefore are highly detrimental. Fine material fills up the openings between the chips, reducing the area and increasing the resistance of the flow of the juice. Thus the character of the cossettes is found to be a most important consideration.

If the cossettes are packed unevenly in the diffusion cells, i. e., if certain portions of the cell contain more chips than other portions, the juice will seek the under-filled portions and circulate much more slowly through the over-filled portions. This exposes part of the cossettes to an excessive amount of juice and part to a very little, leaving some of the cossettes only partly exhausted, which causes a high pulp. This is called "channeling". In order to force the air out of the cell, and to assist in distributing the chips evenly through the cell, the first juice is introduced from the bottom.

The second factor affecting the rate of sugar transference is the ease with which the sugar will pass through the wall of the plant cell, or the permeability of the Osmotic membrane. Heat is used to render the cell wall more permeable, but if this heat is carried too far the structure of the cell will break down and the chips will mass together until the advantage gained through the increased permeability of the membrane is more than offset by the decrease of cossette surface exposed.

Sometimes, in order that the circulation may be freer, the thickness of the chips is increased and the area of cell wall thus decreased. In order to make up for this and for the fact that some of the sugar has farther to travel through the beet structure to get out of the cossette, a higher heat is applied.

To make possible a free circulation without increasing the thickness of the chips too much, chains are hung in the cells so as to form baskets and partially support the weight of the cossettes. These tend to prevent the chips massing together and in this way decrease the tendency toward channeling. It is particularly important that the weight be taken off of the bottom screen as much as possible as it is very easy to fill up the holes in the screen and so greatly slow up the circulation.

A rapid circulation is sometimes prevented by an accumulation of air or gas in the tops of the cells, partially closing off the inlet pipe. This trouble may be remedied by letting it off through the relief cocks in the top of the cells. The presence of gas not only slows up the circulation but indicates that fermentation and destruction of sugar are taking place. The formation of gas may be prevented by neutralizing the acidity of the beets with soda ash.

The third factor influencing the rate of sugar transference is the difference in density between the juice within the plant cell and that without; and assuming the same sugar left in the pulp,

this depends upon the amount of water added to the battery, or as we say, the draft. We are limited in our application of this factor for the reason that all of the water has to be evaporated at the expense of coal and sometimes capacity.

To determine the amount of water added to the battery, or the amount of juice drawn off, all of the raw juice is measured, usually in special measuring tanks, but sometimes in the first carbonation. The "Percentage Draft", which is the percentage by weight of raw juice on beets, is then calculated. For example, 125 draft means that the weight of juice drawn off is 1.25 times the weight of beets sliced.

Efforts should be made to keep the draft as low as possible, for as stated above, all of the water has to be evaporated. If the draft is increased ten per cent, say from 130 to 140 per cent, it means that 100 tons more water will have to be evaporated for every 1,000 tons of beets sliced, which will require about four tons of coal in the boilers. A reduction in draft of ten points would thus save from 400 to 500 tons of coal per campaign at a 1,200-ton factory and from 800 to 1,000 tons at a 2,400-ton factory.

At some factories the evaporators are the limiting factor, or as we say, the evaporators hold the house. At these it is doubly important that the battery draft be kept as low as possible.

The importance of the second function of the battery, "The Separation of the Sugar from the Non-Sugars," is not as a rule realized. Every pound of non-sugar which is not removed in either the diffusion or carbonation process goes into molasses and takes with it one and one-half pounds of sugar, thereby reducing the output of granulated. As sugar in molasses is only about one-third as valuable as white sugar in the bag, it is easy to see the importance of removing in the beet end every pound of impurities possible.

As a measure of the non-sugars removed, the figure "Elimination" is used, which is the percentage of the total non-sugars entering a station or part of the process which is removed from the juice. It may be calculated by the formula:

$$\text{Elimination} = \frac{10{,}000\ (A - B)}{A\ (100 - B)}$$

where "A" is the higher purity, or that of the juice leaving the station, and "B" is the lower purity, or that of the juice entering the station.

The total beet end elimination is accomplished in two stations, the battery and the carbonation. It has been found by study that

the amount of elimination in the battery does not determine that in the carbonation. Or in other words, to get the highest total removal of impurities in the beet end, it is necessary to remove all possible in the battery.

In past years at the various houses the battery elimination has varied from zero to 15 per cent. On 100,000 tons of beets of 85 purity and 15 per cent sugar, 15 per cent increase in the battery elimination would mean 9,000 bags more sugar and 900 tons less molasses, or with 8c sugar and $10.00 molasses a return of approximately $50,000.00 per average campaign at a 1,200 ton factory. It is therefore necessary that we seriously consider the means of securing the highest possible increase in purity between the cossettes and the diffusion juice.

The first consideration is the quality of the battery supply water. All of the non-sugars in solution in the battery supply water go into the diffusion juice and we are safe in saying that at least three-quarters of them find their way into the molasses. The solids in the battery supply water vary from practically none up to 200 parts per 100,000 or 0.2 per cent. If we assume a battery supply water carrying 100 parts solids and 130 battery draft, we will have 2.6 pounds of impurities, or non-sugars, going with the water into the diffusion juice from each ton of beets and two pounds of this finally finding its way into the molasses. On 100,000 tons of beets, this would increase the molasses production 300 tons and decrease the granulated by 3,000 bags.

Not all of the water added to the battery goes into the juice. Somewhat less than half of it remains in the cell and is dumped out with the pulp. At some factories, where the supply of pure water is limited, the piping to the battery is arranged so that the better water can be made to go into the juice and the impure water dumped out with the pulp. Where this double water system is installed it should be used at all times.

The next factor influencing the purity of the diffusion juice is the quality of the cossettes. As stated before, the solution from the ruptured plant cells goes immediately into the juice, impurities and all, without any chance of separating the sugar from the non-sugars. The more of these plant cells that are ruptured, other things being equal, the lower will be the purity of the diffusion juice, and the sharper the slicer knives the smoother will be the chips and the fewer the plant cells ruptured. Fine material in the cossettes means a great many ruptured cells and is therefore to be avoided. Trash in the cutters will mash up the cossettes and

thereby reduce the purity of the diffusion juice as well as slow the circulation.

The third influencing factor is the manner in which heat is applied to the beets. In order to make the cell wall permeable to sugar, it is necessary to apply heat. However, if this heat is too high or used too long, practically the entire beet structure will be broken down, allowing all of the soluble impurities to go into solution, and even in some cases dissolving part of the plant structure. Experience has shown that a high heat on the somewhat exhausted cossettes at the water end of the battery is particularly bad. It is therefore desirable that a short heat be carried at the head of the battery, or in other words, that the maximum temperature be carried on not over five cells when ten or eleven cells are in circulation. It is sometimes necessary to compromise between a long heat and high pulp, but more often, by improving the quality of the cossettes, the pulp may be lowered without excessive heat on the tail end of the battery. Where there are pulp dryers, the detrimental effect of high heat on the pulp is at once apparent on account of the difficulty with which pulp so treated is handled in the pulp presses.

The length of time the cossettes are kept in the battery influences the purity to a considerable extent. Other things being equal, the slower the battery the lower will be the purity of the diffusion juice. On this basis, it is desirable that the battery be just large enough to handle the required tonnage. Where the battery is too large, it is sometimes possible to remedy the trouble partly by keeping fewer cells in circulation.

Fine particles of pulp should be removed from the juice before it is heated and treated with lime, for the reason that they will be dissolved and later unite with the lime to form lime salts, a particularly harmful type of impurity. This fine pulp may be kept out by having the battery screens and measuring tank screens in good condition.

Diffusion juice is susceptible to bacterial action which destroys sugar, particularly at low temperatures. It is therefore desirable that the temperature of the juice be raised as soon as possible after it leaves the battery.

From the above discussion of the diffusion battery, it is apparent that certain fundamental conditions must be fulfilled in order to do good battery work, which may be summarized as follows:

(1) It is necessary to secure a *Maximum Sugar Extraction,* or low pulp, which requires good cossettes, a good circulation and

sufficient heat to render easy the passage of sugar through the walls of the plant cells. The decrease of .03 per cent in the sugar content of the pulp means a saving of 600 bags of sugar per 100,000 tons of beets sliced.

(2) It is necessary to secure the *Maximum Elimination of Impurities,* or the maximum increase in purity between the cossettes and the diffusion juice. This requires pure battery supply water, good cossettes, as little heat as possible on the pulp end of the battery, and a fast circulation. One per cent increase in the elimination of impurities means an increased production of 600 bags of sugar per 100,000 tons of beets sliced. It is interesting to note that one per cent in elimination is exactly equivalent in value to .03 per cent loss.

(3) The extraction should be accomplished with the *Minimum Amount of Water,* or the lowest possible draft. This requires good cossettes, the proper temperature, and a good cell fill. A decrease of 10 per cent in the battery draft means a saving of 500 tons of coal per 100,000 tons of beets sliced, besides in many instances, where the evaporator station is small, it means an increased slicing capacity. A low draft also tends toward an increased purity of Diffusion Juice.

The importance of good battery work in the beet sugar process cannot be over-estimated, for here, to a large extent, is determined the amount of sugar which will finally be turned out in the form of granulated.

OPERATION OF BATTERY

All of the batteries in our factories consist of fourteen cells, averaging about 240 cubic feet per cell. Since there are 3.53 cubic feet in one hectoliter, the average capacity is therefore about seventy hectoliters, or, expressed in tons of beets, about four tons. Batteries of eight or nine cells are often found, particularly in Europe, where the batteries are run more slowly and the sugar left in the pulp is usually higher than in American practice.

We have both side dump and bottom dump cells; the latter have proved the more satisfactory in our experience, as it is easier to discharge the pulp rapidly through the bottom door.

Heating of the battery juice is done by means of juice heaters, called "calorisators", or by direct steam injection. Calorisators are used in nearly all of our factories, the juice being heated by second vapor. Where the juice is heated by direct injection, live steam is used; this, of course, gives poorer coal economy.

In order to save coal and time of heating on the battery, the battery supply water is heated to a temperature of 45° to 60° C. This water is drawn off from the seal tank and is usually quite pure. While some coal can be saved by using water of higher temperature than 60°, this is not good practice, as with such hot water on the pulp end of the battery too many impurities are dissolved, causing low purity juice and low battery elimination.

The quality of the battery supply water is very important and we have spent considerable sums in supplying several of the factories with pure city water, and in installing double battery supply systems. The percentage of total solids in the water usually determines the quality of the water, although this does not tell the whole story. Where the solids consist almost entirely of soda and potash salts, the water is of the poorest quality, as these salts go through into the molasses unchanged while lime and magnesium salts may be largely removed in the carbonation process.

The non-sugars found in diffusion juice are of two kinds, mineral and organic. The mineral impurities consist chiefly of potash and soda salts coming from the beets and the solids of the battery supply water. The mineral non-sugars are far more injurious than the organic non-sugars, as it is practically impossible to eliminate them after the diffusion process. The mineral non-sugars are measured by an "Ash Determination"; the per cent ash in diffusion juice usually runs from .4 to .5 per cent. The figure shown on the laboratory sheets, "Lixiviated ash in diffusion juice," should therefore be watched as well as the purity, and kept as low as possible, in proportion to the Brix of the diffusion juice.

Temperatures.—The maximum temperature which can be carried on four or five cells at the head of the battery varies with the condition of the beets, the size of the cossettes and the speed of circulation. Well ripened beets of high sugar content can stand higher temperatures than green or partially spoiled beets. The maximum temperatures carried usually range from 75° to 83° C. with cossettes of good quality. Lower temperatures must be carried with frozen or bad beets, or the cossettes will soften and pack together, causing "plugged" cells and very slow circulation. It is important when working such beets of poor quality to bring the juice up to the maximum temperature rapidly, as fermentation and formation of gas takes place with too low temperatures and slow circulation. A bad accumulation of gas may almost stop circulation. The presence of gas may be recognized by a slow circulation, excessive

quantity of finely divided foam with a peculiar sweet odor when the juice cocks are opened, and by dark, undiffused cossettes found in the top of the cell when being dumped. The usual remedies resorted to in such cases are to raise the temperature, if too low, draw off juice from the cells with the most gas, or to add soda.

Draft.—The amount of juice drawn depends on a number of factors, such as the quality of cossettese, the extent to which they are packed in the cells, temperatures carried, and the sugar content of the cossettes. The chips should be fine and clean cut, and packed as tightly as possible to secure a low draft. Good cell packing not only gives a lower draft, but should also tend to increase the capacity of the battery.

The calculation of "Draft" is made as follows:

$$\frac{\text{Hectoliters of juice drawn} \times \text{specific gravity of juice} \times 11}{\text{Tons of Beets}} = \text{Draft}$$

which is equivalent to $\frac{\text{Tons of juice drawn}}{\text{Tons of Beets}} = \text{Draft}$

This figure is called the measured or actual draft.

The draft may also be derived by comparing the percentage of sugar in the diffusion juice with that in the beets after deducting the sugar in the pulp and pulp water, by the formula:

$$\frac{\%\ \text{Sugar in Beets} - \%\ \text{Sugar in Pulp and Pulp Water}}{\%\ \text{Sugar in Diffusion Juice}} = \text{Draft}$$

This figure is called the calculated draft or "Draft by Sugar Content", and should compare very closely with the measured draft. In case it does not, an investigation should immediately be made, for it is quite likely that some of the fundamental figures such as the weight of beets, per cent sugar in beets, per cent sugar in pulp and pulp water, are in error, or that the measurement of the raw juice is not correct.

PROBLEMS

Loss of Sugar in Pulp and Pulp Water.—The weight of pulp dumped from the cell has been found to be practically the same as that of beets put in, and the weight of the pulp water is likewise taken as equal to that of the beets put in. This means that the weight of pulp and water dumped from a cell is together equal to

twice the weight of the beets, and to calculate the sugar lost in the pulp and pulp water the following formulas are used:

Example

Let A = Tons beets cut ..... = 2,400
B = % Sugar in Pulp ..... = .18%
C = % Sugar in Pulp Water ..... = .08

$$D = \text{Tons Sugar lost in Pulp} = \frac{A \times B}{100} = \frac{2{,}400 \times .18}{100} = 4.32 \text{ tons}$$

$$E = \text{Tons of Sugar lost in Pulp Water} = \frac{A \times C}{100} = \frac{2{,}400 \times .08}{100} = 1.92 \text{ tons}$$

Total Battery Loss = D + E = 4.32 + 1.92 = 6.24 tons.

(1) A sugar factory slices 208,000 tons of beets during the campaign, the percentage of sugar in the pulp is .21 and in the pulp water is .09. How many tons of sugar are lost in the battery? How many tons of sugar would have been saved if the sugar in the pulp had been reduced to .18% and in the pulp water to .07%? What would be the value of this saving if the sugar is worth three cents per pound?

Evaporation of Water.—When using Quintuple Evaporators every pound of coal burned in the boiler house will evaporate approximately 25 pounds of water. Now with a factory cutting 2,400 tons of beets per 24 hours how much additional water must be evaporated if the battery draft is 140 instead of 130? How many additional tons of coal will be burned?

From the Battery Lecture we learned that

$$\text{Draft} = \frac{\text{Tons of Juice Drawn,}}{\text{Tons of Beets Sliced}} \quad \text{or}$$

Tons of Juice Drawn = Draft $\times$ tons of beets sliced

Therefore, for 140 draft and 2,400 tons beets,

Tons of Juice Drawn = 2,400 $\times$ 1.40 = 3,360 tons

While for 130 draft,

Tons of Juice Drawn = 2,400 $\times$ 1.30 = 3,120 tons.

Additional tons of water to be evaporated is the difference in the "Tons of Juice Drawn" for the two different drafts, or

Additional tons of water to be evaporated = 3,360 — 3,120 = 240 tons

Since one pound of coal evaporates 25 pounds of water,

Additional tons of coal needed = 240 ÷ 25 = 9.6 tons

(2) A sugar factory cuts 210,241 tons of beets during the campaign, and the draft is 132. How many additional tons of water must be evaporated if the draft is raised to 138? How many tons of additional coal will have to be burned and how much will this coal cost at $3.00 per ton?

(3) A sugar factory is cutting 2,275 tons of beets per 24 hours, the draft is 131, the sugar in the pulp is .21% and in the pulp water it is .10%. By increasing the draft to 137, the sugar in the pulp can be reduced to .18% and in the pulp water to .08%. If coal is worth $3.00 per ton and the sugar at this point of the process is worth three cents per pound, should the draft be raised, and if it is raised what net saving would be made?

CHAPTER NO. IV

CARBONATION AND SULPHITATION

SECTION A

When the raw juice comes from the diffusion battery it has the appearance of more or less viscous, violet colored liquid, the color of which deepens more and more as the contact with the air is prolonged. It holds in suspension particles of the tissue of the beet and in solution a considerable quantity of non-sugars, which, without further treatment, would prevent the crystallization of sugar. This makes necessary a further purification of the juice, which is accomplished in the first, second and third saturations.

The general plan of operation is as follows: The raw juice is brought to a temperature of about 85° C,. usually by being pumped through closed tubular heaters heated with second vapor from the evaporators, and a given quantity is measured into the carbonation tanks, where a known quantity of lime (from 2 to 4 per cent on beets) is added. In a non-Steffen house the lime is added in the form of milk of lime and in a Steffen house as saccharate milk, which is a compound of lime and sugar obtained by the Steffen Process. Carbon dioxide gas from the lime kilns is then introduced until a granular precipitate of calcium carbonate is formed and the soluble alkalinity of the solution is reduced to from .090 to .130 grams of CaO (lime) per 100 cubic centimeters of juice. The mixture of juice and precipitate is then heated to about 95° C, either by coils in the carbonation tanks or by another set of heaters, and the precipitate is removed by filtration.

The juice then goes to the second carbonation, where carbon dioxide gas is again introduced until practically all of the lime is removed, and the alkalinity is reduced to about .025 to .035 grams of CaO per 100 cc. The temperature is next raised almost to the boiling point by another set of heaters, and the precipitate is filtered out. The juice then goes to the third saturation, where it is treated with sulphur dioxide gas, made by the burning of sulphur, until the alkalinity is reduced to about .010, and the juice is again heated and filtered.

Of primary importance is the fact that the juice is thoroughly sterilized by the combined action of the lime and the heat, also the quality of the juice is improved by these processes in two ways, first, by removing a part of the non-sugars, and second, by altering

the nature of certain others so as to render them less harmful. The reactions which take place are not thoroughly understood, but it is known that a double action takes place and that the impurities are removed in two ways, by chemical and by mechanical means. On the addition of the lime some of the non-sugars are rendered insoluble and precipitated out, this constituting the chemical purification. When the precipitate of calcium carbonate is formed it surrounds the impurities carried in suspension and so removes them in a mechanical manner.

The first carbonation station usually consists of several tanks, each supplied with means for introducing the juice, lime and gas, and for removing the carbonated material. Various arrangements are used for distributing the gas as it enters the juice, but practically all fall into two general classes: (1) perforated tubes and (2) saw tooth boxes.

In the first class, which is used in practically all Kilby houses, the gas is introduced through pipes or tubes located near the bottom of the tank and perforated on the under side with holes varying in diameter from $\frac{3}{8}''$ to $\frac{3}{4}''$. This type of distributor has the advantage of supplying the gas in small bubbles and so increasing the efficiency of the station, but has the disadvantage that the holes become plugged up with scale and the tubes have to be removed and cleaned at frequent intervals.

With the second type of distributor the gas is introduced under an inverted box, the edges of which are notched, and the gas escapes out through the notches and to a certain extent is broken up. This distributor has the advantage that the boxes may be left in the tanks the entire campaign without attention, but it has the disadvantage that the bubbles are much larger than with the tube type and consequently the absorption of the gas is much slower. Because of the poor absorption it is necessary that the gas, to have the same final exhaustion, travel through a greater column of juice than is necessary with the small bubbles, and consequently with box distributors a higher level is always carried in the tanks than with the gas tubes.

The first carbonation station is usually operated by a first carbonator, or foreman, and one or more helpers. The foreman is responsible for the correct operation of the station and he usually watches the carbonation of the juice to make sure it is of the right alkalinity. The rest of the work, such as filling the tanks, etc., is divided up between the foreman and his helper or helpers.

One of the most common troubles experienced on the first carbonation station is excessive foaming. The juice always foams

during carbonation, but at certain times, due to the condition of the beets, the amount of foam is greatly increased. To take care of the spent gas which comes off the tanks, vent stacks are provided, each of which is connected by a "goose neck" to a header, usually located on the roof of the factory, and so arranged as to drain back into the carbonation tanks. When the juice foams excessively, the foam passes up through the vent stack into the header and back ususally into another carbonation tank, causing the mixing of juice of varying degrees of saturation. Besides making it difficult to get even work on the station this foam actually hurts the quality of the juice. The best remedy for this trouble is plenty of space in the tanks above the juice level so that the foam will not pass out through the vent stacks. The common practice is to break the foam with cottonseed oil, which is a satisfactory method where there is not sufficient tank space above the juice line. When excessive foaming suddenly develops, with no apparent change in the beets. it is well to investigate the gas distributors to see if they are all right, for if a tube distributor is put in upside down so that the openings are on the top side of the tube, the velocity of the gas through the liquid is increased and excessive foaming results. With box distributors, if the boxes get out of level the gas will escape in large bubbles from the high side of the box and increase the foaming.

Recently a new type of apparatus, known as the Naudet continuous carbonation, has come into use. With this system the lime is mixed with the juice in a defecating tank, which is simply a large tank equipped with a stirring device. The juice and lime, together with the gas, are introduced at the top of the mixing column, which is a cylindrical tank two or three feet in diameter and about twenty feet high with a conical bottom. In this tank an intimate mixture of the juice and gas is formed and about one-fourth or one-third of the chemical reaction takes place. This mixture then passes out of the bottom of the mixing column into the bottom of the carbonation tank, which is about five feet in diameter and about twenty-four feet high. Here the carbonation reaction is completed, the spent gas passes off through a stack at the top and the carbonated liquor passes out through a pipe into a receiving tank. A float chamber is connected to the carbonation tank and the float therein regulates the juice inlet valve. When the juice is properly carbonated the viscosity is such that a certain level is maintained above the outlet pipe. If the juice is under-carbonated the level rises, carrying the float, which partially closes the juice inlet valve; if over-carbonated the level falls and

the float opens the juice inlet valve. It is intended in this way that a constant alkalinity be held automatically, however, in actual practice the constant attention of a workman is required to do good work. Our experience has shown this apparatus to be very efficient from the standpoint of non-sugar elimination, but poor from the standpoint of gas absorption.

After the impurities precipitated at first carbonation are filtered out, it is possible to remove the lime still in solution by treating further with carbon dioxide, and this is done in the second saturation station where the alkalinity of the juice is reduced to about .025 to .035 gram CaO per 100 cc. It may seem strange to one not entirely familiar with the beet sugar process why it is necessary to have two carbonations and why all of the lime is not removed in the first carbonation. The reason for this lies in the fact that certain of the organic impurities, when combined with lime, are insoluble in an alkaline solution, but are soluble in a neutral or acid solution. We therefore endeavor in first carbonation to hold the alkalinity at such a point that these impurities are insoluble and may be filtered out. In order to remove the remainder of the lime we treat with carbon dioxide at a separate station after the impurities have been filtered out.

The second carbonation station usually consists of three or four tanks and is operated continuously, i. e., the juice overflows from one tank to the next successively. The gas is supplied continuously, the amount being regulated by testing the outgoing juice at frequent intervals. The temperature at which the saturation takes place at this station is determined usually by the temperature of the juice leaving the first presses, which is between 87° and 90° C, and the alkalinity of the outgoing juice should vary within narrow limits, for if this alkalinity is too high, a considerable amount of lime remains in solution which must be precipitated out in third saturation by means of sulphur dioxide, and since the resulting calcium sulphite is more soluble than calcium carbonate. the amount of lime salts will be increased. If the alkalinity is too low, sufficient sulphur dioxide cannot be used in the third saturation to prevent the color of the juice from suffering.

The juice, after second carbonation, is again heated almost to the boiling point before going to the second presses for the same reason that the juice is heated before going to the first presses, i. e., to secure a better filtration.

From the second presses the juice goes to third saturation, where it is treated with sulphur dioxide gas until the alkalinity is

reduced to about .010 gram of CaO per 100 cc. The sulphur dioxide gas is made by burning sulphur in an atmosphere of air, and in the older installations the air is supplied to the stoves under pressure. One of the main troubles experienced is that the gas pipes become stopped up with sublimed sulphur. To prevent this the stoves are equipped with cooling chambers which are intended to cause the unburned sulphur to deposit before it reaches the piping. More or less trouble is experienced, however, especially when the stoves are run at high capacity.

A sulphur stove of improved design consists of a horizontal iron cylinder which rotates slowly. The gases pass from the stove into a combustion chamber, where any vaporized sulphur can be completely burned by admitting a suitable amount of air. Following the combustion chamber is a "cooler" by which the temperature of the gas is reduced within a safe limit. This type of stove is operated under induced draft.

The mechanical arrangement of the third saturation station is commonly the same as that of second carbonation, but at a few factories a saturating tower consisting of a high cylindrical tank filled with baffles is used. The gas is sucked into the bottom of the tank and rises through the baffles, while the exhausted gas passes out through a stack at the top. The juice enters at the top and is distributed over the baffles, and, as it flows downward through the stack, meets the rising gas and becomes saturated. This type of sulphur station, which is known in our company as the Graham Sulphitor, has proved quite satisfactory in practice.

The object of the third saturation or sulphur station is to remove or break down some of the coloring matter in the juice and thus improve the color of the sugar. While it is questionable whether any impurities are actually eliminated in the sulphur station, there is no doubt that juices so treated hold their color better during evaporation and boiling and yield a better quality of sugar.

The carbonation process offers the last opportunity to remove impurities from the juice and any impurities which pass this station must finally find their way out in the molasses where every pound of impurities will take with it one and one-half pounds of sugar. For this reason the highest possible increase in purity between the diffusion juice and the thin juice should be obtained and at the same time a filter press cake must be produced which will wash easily. The following points will assist the operator in securing good carbonation work:

(1) The temperature of the juice entering the carbonation should be even, usually about 85° C.

(2) The same amount of diffusion juice should be drawn into the tanks each time.

(3) Sufficient lime should be used to secure a good, granular precipitate and the same amount of milk of lime or saccharate should be added to each tank, for if this is not done, unevenness of carbonation and decreased impurity elimination will result. The milk of lime and saccharate measuring tanks should be kept clean so that an accurate measurement may be made.

(4) At Steffen houses the saccharate milk should be heated to the proper temperature (85° to 90° C).

(5) An even alkalinity, usually from .090 to .130, should be carried, for any large deviation from these limits will make for inferior work. If the alkalinity is much lower than .090, certain of the impurities will be redissolved and increase the loss of sugar in molasses, while if the alkalinity is much higher than .130 the juice will be difficult to filter, the lime cake will be hard to wash, and higher sugar losses in the filter presses will result. If through accident a tank is carbonated too low, the trouble may be partially remedied by taking in an additional quantity of lime and recarbonating.

(6) The dropping of a "raw" or uncarbonated tank has very serious results, for juice of this kind will gum up the presses and increase the losses in lime cake and molasses.

(7) The temperature of the juice entering the first presses should be even, usually from 90° to 95° C.

(8) Each tank should be well emptied before drawing in new raw juice but at no time should CO_2 gas be turned on to help empty the tank.

(9) Milk of lime or saccharate should not be added until the tank is ready for the gas, since a portion of it will settle out, remain undecomposed by the gas, and cause trouble in the presses.

(10) As soon as a tank is carbonated and heated it should be sent to the presses.

(11) The juice should be carbonated as rapidly as possible, for fast carbonation produces juice of the highest purity.

(12) The juice should be heated almost to the boiling point before filtration.

(13) The carbonator should at all times watch the filter press cake, for if, without other irregularities, smeary cake results, leaky inlet or outlet valves should be expected and searched for.

The above points apply largely to first carbonation, but for good work every attention should be paid to second and third saturation to see that even work is done. The neglect of these stations may easily cost 2,000 bags of sugar per campaign at a 1,200-ton factory and twice that amount at a 2,400-ton house.

QUESTIONS FOR DISCUSSION

(1) What method would you use to locate the trouble if the first juice filtered slowly and the alkalinity was apparently correct?

(2) If it were found impossible to get sufficient gas from the kilns to carry on the carbonation, what steps should be taken to remedy the trouble?

(3) What are the reasons for having two carbonation stations?

(4) What should be done and what points investigated when juice foams excessively?

SECTION B

Although the double carbonation and sulphitation process has been in use for a number of years, all of the reactions which take place are not understood. However, enough knowledge of the phenomena has been gained to establish the general principles necessary for the intelligent conduct of the process.

When milk of lime is added to a sugar solution, more lime will be dissolved than in pure water. This extra lime is approximately sufficient to form with the sugar the mono-calcium saccharate, which is a combination of one molecule of sugar and one molecule of lime. If the juice saturated with lime is heated almost to the boiling point, the solution becomes cloudy and some insoluble tri-calcium saccharate is precipitated. The precipitate will not decompose until the solution is almost neutralized with CO_2. This fact shows that a solution of sugar saturated with lime should not be heated before treatment with CO_2 if a considerable loss of sugar in the filter presses is to be avoided. For this reason the juice should be brought to the proper temperature before the lime is added, and

no more heating done until the treatment with CO_2 is complete, when there is no further danger of forming the tri-calcium saccharate.

The non-sugars in the juice are composed of a mineral or inorganic part and an organic part, which may likewise be divided into two groups, namely, the nitrogenous and non-nitrogenous materials.

The action which the lime exerts on the non-sugar is quite variable. The phosphoric acid which is found in large part in combination with albuminoid substances is freed by the action of the lime and precipitated in the form of tri-calcium phosphate, and is so eliminated from the juice. Some of the other inorganic acids, such as sulphuric and silicic, also unite with the lime but are only partly insoluble and are so only partly eliminated. Some of the others, such as hydrochloric and nitric, form soluble calcium salts and remain in the juice; these acids are, however, found in very minute quantities. Among the bases the fixed alkalies, sodium and potassium, which constitute a considerable portion of the non-sugar element, are scarcely eliminated at all. These remain in the juice and pass along into the molasses. Some of the other bases are not affected by the lime but are eliminated by treatment with CO_2.

The non-nitrogenous organic impurities consist essentially of the organic acids, of which oxalic is the most important. This forms a partially insoluble compound with lime and so is partially removed. Numerous other organic acids may be present in the juice but their nature is not well known and depends upon the nature of the beets. Another group of substances which come largely from the fiber of the beet known as pectic substances behave in different ways in the presence of lime according to the forms in which they exist in the juice. Some are altered so as to be less harmful and others are precipitated out. The juice besides the regular sugar contains two other sugars, raffinose and invert sugar. The raffinose is not removed in the carbonation process and goes through into the final molasses. The invert sugar is decomposed into acids which combine with the lime to form colored lime salts. The presence of invert sugar in the raw juice therefore gives the purified juice a decided coloration and increases the quantity of lime salts.

The nitrogenous impurities of the juice are more or less complex and form three principal groups, the amides, albuminoids, and vegetable bases. The amides undergo a more or less complete transformation and their decomposition gives place in part to a liberation of ammonia and in part to residuary acids which unite

with the free alkalies of the juice or with the lime to form lime salts. The albuminoids are coagulated and are carried out in the lime cake. The lime has very little influence upon the vegetable bases.

Upon treating the defecated juice with CO_2, insoluble calcium carbonate is formed, also a very small amount of other insoluble carbonates. This precipitate surrounds the other insoluble materials in the juice and carries them out.

Although the alteration of the impurities left in the juice by the carbonation process is a very important feature, it is difficult of measurement and therefore the quality of the first carbonation work is ordinarily judged by the quantity of non-sugars actually removed from the juice. This is expressed by the percentage of "Elimination" having the same meaning and calculated by the same method as shown in connection with the lecture on the Diffusion Battery, i. e., "Elimination" means the percentage of total non-sugars entering a station or part of the process which is removed from the juice and may be calculated by the formula:

$$\text{Elimination} = \frac{10{,}000\ (A - B)}{A\ (100 - B)}$$

where "A" is the purity of the juice leaving the station and "B" is the purity of the juice entering the station.

However, at Steffen houses, before it is possible to determine the elimination, it is necessary to calculate the purity of the first carbonation juice from the beets by eliminating the effect of the saccharate upon the juice purity. This may be calculated by the following formula:

P_1 = Purity of first carbonation juice.

P_2 = Purity of saccharate cake.

S_1 = Net sugar to first carbonation from beets.

S_2 = Net sugar to first carbonation from Steffen.

P_3 = Purity of beet juice after first carbonation.

$$P_3 = \frac{(S_1 + S_2)\ P_1 - S_2 P_2}{S_1}$$

The carbonation elimination varies from 20 to 30 per cent and usually lies between 24 and 28 per cent. As one per cent in elimination means a difference of 600 bags of sugar per 100,000 tons of beets sliced, it is important to obtain the highest possible increase in purity between the diffusion juice and the first carbona-

tion juice. At the same time, it is necessary to secure a precipitate which will wash easily so that the sugar left in the lime cake will be reduced to a minimum without using an excessive amount of wash water.

Bearing these points in mind, we may then discuss the carbonation process from the standpoint of: First, defecation; second, carbonation; and third, treatment after carbonation.

The first variable condition of defecation is the temperature at which it is carried on, or the temperature to which the raw juice is heated before the lime is added. Experience has shown that heating to 85° C seems to give the best results. If heated much above this point, the absorption of the gas becomes slower and excessive foaming takes place during the carbonation, while if the temperature is too low, a poor precipitate is formed which is difficult to filter and wash, and a high loss of sugar in the press cake results.

At the Steffen houses it is very important that the saccharate milk be heated to at least 85° C in the mixing tanks, since, if this is used too cold, the press cake will contain a large amount of sugar combined with the lime and it will be impossible to secure a reasonable sugar loss.

The second variable of defecation is the amount of lime added. At the Steffen houses this is largely determined by the amount of molasses worked, i. e., all of the lime added to the coolers in the Steffen houses, except a small portion lost in the waste water, must be added to the carbonation. It has been demonstrated experimentally that the amount of lime added over and above 1.5 to 2.0 per cent on beets does not materially affect the purity of the resultant juice except as the filtration is improved. All of the extra lime added, above that required to give a freely washing press cake, increases the sugar loss, and we therefore conclude that, except possibly in the case of very bad beets, only sufficient lime should be added to give a good, granular precipitate. It is necessary, however, in order to assure even work at first carbonation, that the amount of lime added to each tank be practically the same. For this reason the Brix of the saccharate milk or the milk of lime, as the case may be, should be kept as uniform as possible, and about 30° Brix for the saccharate milk, or 40° Brix for the milk of lime, has been found by practice to be the best density.

Some authorities recommend allowing the lime to stand in contact with the juice for some time before the introduction of the

carbon dioxide gas; this is done in a special "defecating tank" provided with means of agitation. How much actual benefit is derived is doubtful, and our factories are not usually provided with special defecating apparatus.

On the introduction of the gas certain reactions, not fully understood, take place. Calcium carbonate and the double salt of cal cium carbonate and calcium sucrate are formed which thicken the juice and give it the heavy appearance familiar to the operators. As the saturation continues, the double salts are broken down, and when the proper alkalinity is reached, a granular precipitate, which settles out rapidly, is formed. This precipitate surrounds the insoluble impurities, those present in the raw juice as well as those thrown out of solution by the action of the lime, and it is then possible to filter the juice readily.

The temperature at which the carbonation is carried on is determined by the temperature of defecation, which, as stated before, should be about 85° C, and by the time the saturation is complete this temperature will have been reduced to about 80° C.

The second variable is the extent to which the saturation is carried, or the alkalinity of the filtered first juice. Investigation has shown that within *reasonable* limits this does not influence the purity of the resultant juice and that, if the saturation is carried on only until a good precipitate is formed, no trouble will be experienced. If the saturation is not carried far enough, all of the calcium sucrate will not be broken up, the precipitate will be difficult to filter out and high sugar losses in the press cake will result. If the saturation is carried too far, the organic non-sugars, lime salts and coloring matter, thrown out by the defecation, will be redissolved, giving an impure, dark colored juice which filters with great difficulty.

The alkalinity of the carbonated juice is made up of the alkalinity due to lime and the alkalinity due to the natural alkalies of the beets. The granular precipitate which is most easily filtered out forms in the juice when the alkalinity due to the lime is at about a certain point. The alkalinity due to the bases in the juice varies with the nature of the juice and with its concentration. It is then easily understood that no definite figure may be named as the point to which the saturation should be carried in the first carbonation. This explains the difference always noted in the first juice alkalinity between Steffen houses and non-Steffen houses; a

considerable quantity of bases, other than lime, is carried into the juice with the saccharate milk. In general, however, it is found to be the best practice in normal operation to carry the alkalinity between .090 and .130 grams of CaO per 100 cc. of juice. Whatever may be the figure, the evenness of the alkalinity is a good indicator of the regularity in the operation of the station and therefore a good indicator of the efficiency.

The third variable is the rapidity with which the saturation is carried on. It has been demonstrated that this is the principal factor determining the percentage of elimination, and the more rapidly the carbonation is carried on, the greater will be the quantity of the non-sugars removed, which would indicate that it is well to give some attention to the factors which influence the rate of carbonation.

The first factor influencing the rate of carbonation is the amount of juice carbonated per tank, or the depth of the liquor through which the gas passes. The farther the gas has to travel through the juice, the more complete will be the absorption of the CO_2 and the more exhausted will be the bubbles which reach the surface, and since the rate of absorption decreases as the percentage of CO_2 in the gas decreases, a high level in the carbonation tank tends to slow up the saturation and is therefore harmful. If, however, the depth of the juice is decreased too much, the exhaustion of gas is decreased to such an extent that it becomes impossible to supply enough gas to complete the saturation, and in addition to this, excessive foaming develops in the tanks. The best condition is, therefore, a compromise between two extremes and it has been found in practice that from 4 to 5 feet of juice is the proper amount to be carried in the tanks.

The higher the carbon dioxide content of the gas, the more rapid will be the absorption and consequently the more quickly will the saturation be accomplished. Care should be taken to have the CO_2 content of the gas as high as possible and methods of accomplishing this will be discussed later under the subject of Lime Kilns. Some tests made at Longmont several years ago show the following effect of increased carbon dioxide content in the gas:

Per cent CO_2 in Gas Entering	36.4	32.2
Time to Carbonate Tank, minutes	7.8	10.1

Another important factor, and probably the most important factor for rapid saturation, is the proper distribution of the gas

as it enters the juice. The rate of absorption is directly proportional to the area of gas exposed to the juice and this depends upon the size of the bubbles, since for a given quantity of gas the bubble area is inversely proportional to the diameter of the bubbles. This means that if gas is introduced into one tank in one-inch diameter bubbles and the same amount of gas is introduced into another tank in one-half inch diameter bubbles, the bubble area exposed in the latter will be twice as great as in the former and the absorption of the carbon dioxide twice as rapid.

The type of distributor used determines the size of the gas bubbles. As stated in Section A, the tube type distributor gives much smaller bubbles than the inverted boxes. A very small increase in purity will pay for the expense of cleaning the tubes so that our preference is decidedly in favor of gas tubes rather than boxes. The Naudet carbonation gives rapid and even saturation and experience has shown it to give a high elimination of non-sugars. A distributor in which the gas is introduced through a centrifugal impeller in the bottom of the tank has been used. This gives a good gas distribution and a high elimination of non-sugars.

Probably the most important factor after the saturation is completed is the length of time that the juice is held in process before filtration. The longer the juice is in contact with the precipitate, the more impurities will be dissolved back and the poorer will be the quality of the final juice. It is a common practice at some factories, where the first press capacity is limited, to have three or four tanks full of carbonated juice waiting to be filtered. This practice should be carefully guarded against. At most factories receiving tanks are provided between the carbonation and first press pump and these tanks are beneficial in that they help the press work by giving an even flow of juice to the presses, but they should not be used as storage tanks and the amount of juice in such tanks should be kept as small as possible. If, however, it is necessary to hold juice at this station, it is preferable to hold carbonated juice rather than raw juice.

The second variable after saturation is the extent to which the juice is heated before filtration. While this probably has very little influence on any chemical reactions, the physical effect of heating the juice up to about 95° C is highly beneficial. The juice is rendered less viscous and the filtration much easier, so that the cake can be washed more readily.

Before going to second carbonation the juice should be thoroughly filtered, as a great many of the non-sugars which are insoluble at the alkalinity of first juice are soluble at that of second juice. Poor filtration at the first presses will give a dark colored final juice rich in lime salts.

In the second carbonation there takes place a complete or almost complete elimination of the lime from the juice. Also, certain non-sugars which are more soluble in an alkaline solution than in a neutral solution are precipitated out. The amount of these, however, is not enough in actual practice to affect the purity of the juice appreciably. The degree of alkalinity which should be carried on second juice varies considerably with the nature of the material handled, but it is well to bear in mind that either too high or too low an alkalinity of second juice is very likely to scale up the heating surfaces of the evaporators. In general practice it has been found best to carry an alkalinity of .025 to .035 grams of CaO per 100 cc. of second juice. After the saturation is complete the juice should be reheated nearly to the boiling point in order to assist filtration and also to remove certain lime salts which are less soluble at high temperatures.

In the third saturation the juice is treated with SO_2 gas until the alkalinity is reduced to about 0.10 grams CaO per 100 cc. Although in this station it is doubtful if any impurities are eliminated, the general quality of the juice is improved by breaking up certain coloring matters and otherwise rendering less harmful the non-sugars remaining in the juice. It has also been found beneficial to heat third juice almost to the boiling point before filtration.

Note:—We are indebted to Mr. Eug. Stuyvaert for considerable of the technical information given in this lecture.

PROBLEMS

(1) In a non-Steffen factory the purity of diffusion juice was 85.0 and of first carbonation juice 88.4. What percentage of the impurities was eliminated?

(2) A factory sliced 1,156 tons of beets with a battery loss of .18 per cent sugar in the pulp and .09 in the pulp water. The sugar in the cossettes was 15.80. How many tons of impurities were eliminated, using the purities as given in No. 1?

(3) If the purity of first carbonation juice had been 89.5 in the previous two problems and the molasses purity 60, how many additional bags of sugar would have been produced for this day's work? Disregard all other losses.

(4) Make up a problem for yourself and show what it means to the factory when the first carbonator produces juice of 88.5 purity instead of 88.0 purity.

CHAPTER NO. V

FIRST, SECOND AND THIRD FILTERS

SECTION A

The precipitate which is formed in the first carbonation process is removed from the juice in the first presses. The work performed here is entirely mechanical and consists simply in seperating the insoluble solids from the juice; and the efficiency of the filter station is measured by the completeness with which this is done; or, in other words, how little of the precipitate is left in the juice, as indicated by the clearness of the juice leaving the station, and how little of the juice is left with the precipitate, as indicated by the amount of sugar left in the lime cake.

With all types of filters now in use the general procedure is the same. The mixture of juice and precipitate is pumped into the filter; the juice, after being filtered through, passes out of the filter leaving the precipitate deposited on the cloth in the form of lime cake from which the sugar is removed by washing the cake with water.

To get the best results in the operation of any filter station, the following conditions should obtain:

(1) A minimum amount of precipitate left in the juice.

(2) A minimum amount of sugar left in the lime cake.

(3) The smallest amount of wash water which will reduce the sugar in the cake to the proper point.

(4) As little labor and filter cloth as will do the work satisfactorily.

The filtered juice must be clear because the pricipitate contains impurities which would be redissolved when the alkalinity of the juice is reduced in second carbonation. In this way some very harmful non-sugars, particularly lime salts, would be put back into the juice, and cause trouble in all the rest of the process. The juice should leave the first filter station light yellow in color and clear and sparkling.

Little sugar should be left in the lime cake, because the cake goes straight to the sewer after it leaves the filter. Unwashed cake contains about 7% sugar and 90% of this should be removed in washing, leaving only 0.7% in the cake which cannot be profitably

saved. Poor work in first carbonation may leave some of the sugar chemically combined with lime in such a way that it is insoluble, and cannot be removed by washing, but with reasonably good work this insoluble sugar should not be more than 0.2% or 0.3% of the cake. The rest of the sugar is in the form of juice; and, if the work is properly handled, it pays to wash out this juice until the sugar left amounts to only 0.4% to 0.5% of the lime cake. The total quantity of sugar in the washed lime cake, therefore, should not be more than 0.6% or 0.8%.

The quantity of first lime cake varies from 10% to 20% on the weight of beets, depending on the amount of lime used at first carbonation. A difference of 0.10% in the amount of sugar left in the lime cake, therefore, is equivalent to a gain or loss of 240 bags of sugar in a non-Steffen factory cutting 100,000 tons of beets in a campaign. At a Steffen factory cutting the same quantity of beets, the loss would be about 360 bags, because more lime is used; in a Steffen factory cutting 200,000 tons of beets, the loss would be 720 bags.

Beside the sugar actually left in the cake, some juice may leak from the filter into the scroll which carries the cake away. When this occurs, the ratio of sugar to calcium oxide will be higher in the samples taken from the lime flume than in cake taken directly from the filters. Both of these ratios are shown on the laboratory sheets as "Sugar to 100 CaO," and can be used for calculating the quantity of sugar lost through leaks. In calculating sugar extraction, The Great Western Sugar Company considers this loss unaccountable.

The smallest possible amount of wash water must be used, because it all has to be evaporated at the expense of coal, and sometimes, when the evaporators are small, at the expense of factory capacity. The quantity of water used varies from 80% to 180% of the weight of the cake, according to the efficiency of the station and care used in its operation. A difference of 10% on the weight of cake is equivalent to a difference of 1,200 tons in the quantity of water which must be evaporated and 50 tons in the quantity of coal which must be burned, during a campaign in a non-Steffen house cutting a total of 100,000 tons of beets; 1,800 tons of water and 75 tons of coal in a Steffen factory cutting the same quantity of beets; and 3,600 tons of water and 150 tons of coal in a Steffen factory cutting twice as many beets. Therefore, use the smallest feasible amount of water; but do not save water at the expense of much sugar, because, ordinarily, any sugar in excess of about 0.7%

in the cake will more than pay for the coal required to evaporate the water used to remove it.

Labor and filter cloth are direct expenses chargeable to the operation of the filter station and both should be kept as low as is consistent with good work.

Two types of filters are used by The Great Western Sugar Company for first filtration: plate and frame filter presses and Kelly filters. (See Plates Nos. 5 and 6.)

The plate and frame presses consist essentially of heavy metal frames between the side bars of which, and at right angles to them, cast iron plates and frames are placed alternately, with the cloth filtering medium between. The frames are of various thicknesses, usually about one inch; the faces are planed smooth to make a tight joint with the plates and the inside edges are slightly beveled, to facilitate removal of the cake; channels and ports are provided for introducing the unfiltered mixture of juice and lime precipitate into the open spaces of the frames. The plates have planed faces to match the faces of the frames, and the space bounded by these planed faces, corresponding to the open part of the frames, is corrugated to allow the passage of the filtered juice as it comes through the cloth. Channels and ports are provided for removing the filtered juice and for introducing and removing the wash water. The juice and wash water usually leaves each frame through a cock at one of the lower corners, so that broken or defective cloths are easily detected by observing the liquid discharged by these cocks. The two end frames of the press fit against the heavy head plate and the foot plate respectively. The head plate is fixed, serving usually as a part of the frame; and it contains the unfiltered juice and the water inlets to the press. The foot plate is movable and by applying pressure to it through a screw or a hydraulic piston, for example, all the frames and plates are bound so firmly together that juice cannot escape through the joints between them, the filter cloths acting as gaskets. This is why plate and frame filters are called presses; other types should be called filters, not presses.

The *dressing* of a press is the operation of placing the cloths (or other filtering medium) between the plates and the frames.

In *filling* a press, juice is pumped into it until filtrate practically ceases flowing, and if the carbonation has been properly carried out the frames will then be completely filled with a firm solid *cake* of the lime precipitate.

One of the first problems is that of capacity. If the presses are holding the house, the first remedy is to increase the pressure of the juice, as experiments have shown that the amount of liquid which will be forced through the cake and cloth is almost directly proportional to the pressure applied. However, if the pressure is too great the precipitate will be forced through the cloth and some of the frames may even be broken. Experience has shown that 40 pounds per square inch is about the proper pressure to carry on plate and frame presses. The two most common causes of slow filtration are, (1) reduction of the filtering areas on account of pressing the cloth into the corrugation of the plates, and (2) forcing the cloth into the outlet ports in the corners of the plates. Both of these evils may be remedied by covering the corrugated faces of the plates with wire screen of about quarter inch mesh, to support the fabric.

Care should be taken that all of the inlet ports to the mud frames are always free, lest some of these frames fail to fill and the unequal pressure thus caused break the juice plates.

At some factories, particularly where the press station is small, much trouble is experienced with juice leaking out between the sections of the filter. This is usually caused by cake on the faces of the plates and frames, so that a good joint is prevented. As anything which tends to increase the capacity of the station allows more time for taking care of the presses and so helps prevent leaks, screens on the corrugated plates, as mentioned above, are beneficial from this standpoint also. The machined faces of the frames should be thoroughly scraped at least twice in twenty-four hours to remove any cake that may adhere. The press should be filled until a firm cake is made, so that it can be easily dumped. In order that any juice which does leak out will not go into the scroll, removable pans are placed under the presses while they are being filled. Care should be taken that these pans do not drain into the troughs carrying the filtered juice; they should drain into a separate line to be pumped again through the filters. The pans themselves must be kept perfectly tight.

The amount of wash water used on the plate and frame filters varies greatly and depends somewhat on the nature of the cake but much more on (1) the extent to which the sugar is washed out, (2) the tightness of the presses and (3) the general care with which the station is operated. Experience has demonstrated that for a low amount of wash water, slow washing is essential on these presses and for this reason almost all of our presses are equipped

Plate No. 5.

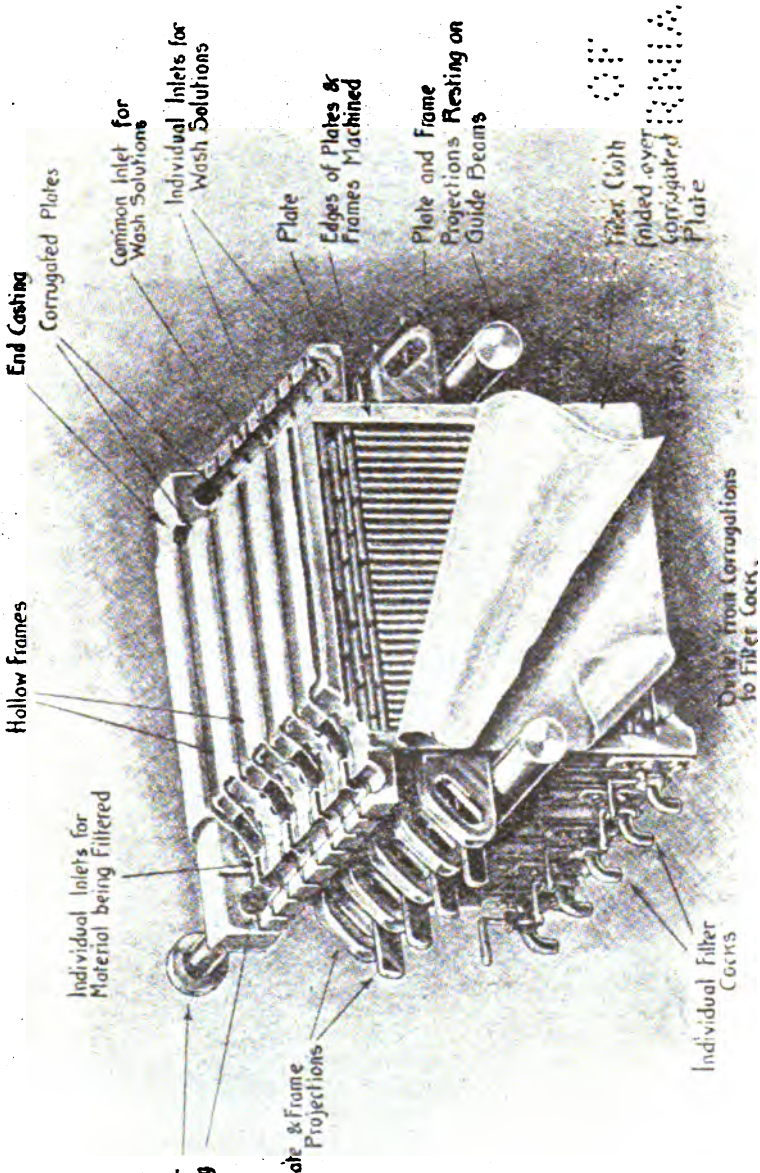

End Casting
Corrugated Plates
Common Inlet for Wash Solutions
Individual Inlets for Wash Solutions
Plate
Edges of Plates & Frames Machined
Plate and Frame Projections Resting on Guide Beams
Filter Cloth folded over Corrugated Plate
Hollow Frames
Individual Inlets for Material being Filtered
Outlet from Corrugations to Filter Cock
Plate & Frame Projections
Common Inlet for Material being Filtered
Individual Filter Cocks

PLATE AND FRAME FILTER PRESS

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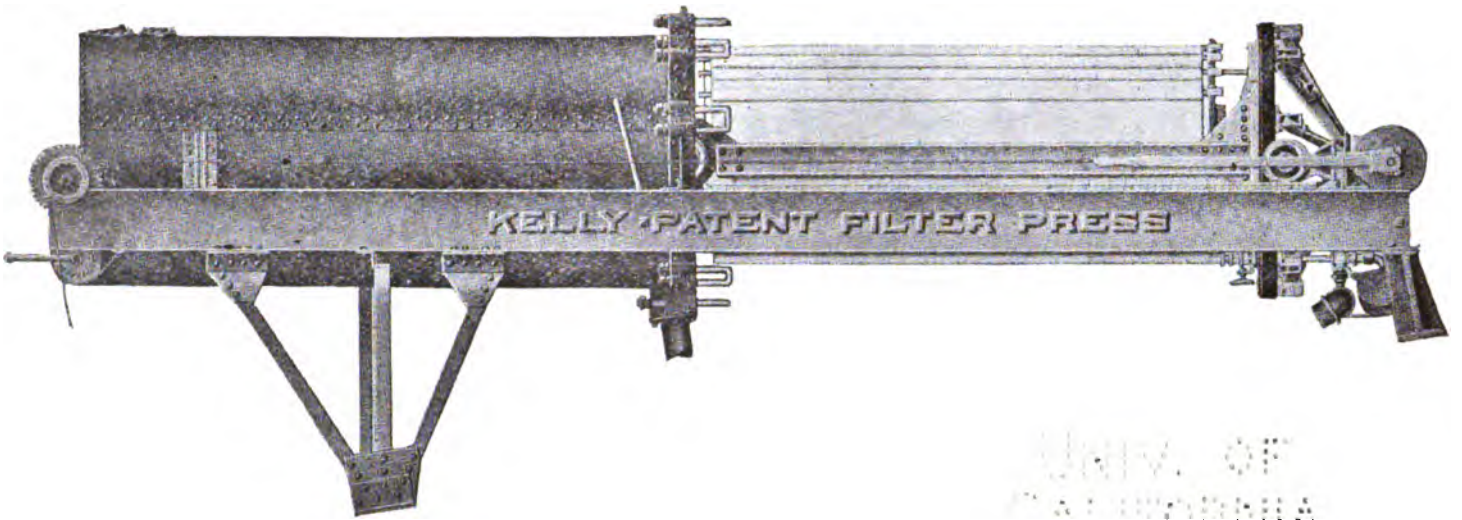
Plate No. 6.



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with a small wash water inlet. Trouble sometimes occurs on account of the cake's channeling; that is, holes washing through the cake. Holes may be caused by incomplete filling of the press so that there is little, if any, cake in the tops of the frames; or it may be caused by the cake's pressing the cloth into the corrugations of the plates until the wash water cannot get behind the cake; consequently all of the water passes through the cake near the inlet. The latter fault is remedied by the screens on the frames and the former by more care in filling the press.

Probably the most common causes for excessive wash water are careless washing and running more water through some presses than is necessary to reduce the sugar content of the cake to the proper point. The washing should be discontinued when the density of the water leaving the press is one to three degrees Brix.

Plate and frame presses of sufficient capacity, when properly handled, will give good, clear filtration and low sugar loss in the cake, with a reasonable amount of wash water. All that is necessary to give the best results is to keep the presses clean and free from leaks, fill the frames evenly with a good, firm cake and wash until the water leaving the press is down to the proper Brix.

The Kelley filter consists of a sheet metal cylinder closed at one end. The other end can be closed by a cast iron head attached to a traveling filter carriage mounted on wheels. The filter frames are rectangular in shape, made of wire screen covered with bag-shaped filter cloths and placed lengthwise four inches apart in the filter carraiges. Each frame has an outlet pipe extending from the interior of the bag through the cast iron head to a header pipe outside which leads into a juice- and water-box located at the side of the press. Attached to the cast iron head is a quick-locking device which presses the head against a gasket around the end of the cylinder and closes the filter. An air motor usually pulls the carriage in and out of the shell with a telescopic motion.

The method of operation is as follows: The unfiltered material is introduced into the interior of the shell through an opening at the bottom. The air within escapes through a float chamber and blow-off valve attached to the top of the press. When the shell is full, the float rises, closes the air valve and prevents liquid from getting into the air line. When the leaves are all submerged and filtration begins, the clear liquor is forced through the filter bag and out the individual outlets into the juice-box, leaving the cake adhering to the outside of the bag. This continues until a cake of sufficient thickness is formed, when a drain valve at the bottom of

the shell is opened to let the excess juice flow out. As soon as the juice level falls, the float valve on the top of the cylinder opens and admits air at 5 to 10 pounds pressure; this forces the juice out and holds the cake in place. As soon as the cylinder is empty, water is pumped in from the bottom, forced through the cake and drained into the sweet water box until the Brix of the sweet water indicates that washing is complete. Then the excess water is drained out of the shell into the excess water tank, to be used for the first washing on the next press. The frames bearing the cake are pulled out of the cylinder, and the cake is removed by washing with high pressure water from a hose. This operation is sometimes assisted by inflating the bags with air. The cake is thus cracked and more easily removed. After cleaning and closing the filter it is ready for another cycle.

To get satisfactory results from a Kelly filter, great care must be exercised in its operation. Several things which may easily be neglected are essential for low sugar loss:

First, the air-pressure should be held on the cylinder all the time while the filter is being filled and washed. When the shell is full of liquid, the float-valve is closed to prevent its escape through the air line; as soon as the level of the liquid falls, the float-valve opens and allows the air to enter the shell again. This holds the cake in place until the juice- or water-pressure is renewed. If, now, the air pressure is not maintained constantly and the liquid-pressure should fail, patches of cake will peel off from the filter-cloth and fall into the bottom of the shell. This will leave bare or thin spots on the filter-cloth, through which a large proportion of the wash water will pass, leaving the rest of the cake poorly washed.

Second, the air pressure should not be too high; experience has shown that six or seven pounds is most suitable in sugar house work: it should not be applied too long, by allowing the cake to stand incompletely covered with liquid. In either case, too high a pressure or a suitable pressure applied too long, an excessive amount of air will blow through the cake, dry it out and crack it and most of the wash water will pass through the cracks and leave the cake unwashed. Therefore, as soon as the cake is thick enough, the juice should be quickly drained from the shell, and the washing started without delay. It is not good practice to fill the filters faster than they can be washed.

Third, the filter must not be allowed to run so long that the cakes on adjacent frames build out too close together, because then they cannot be properly washed. A little laxness of attention may

let the cakes build clear across and completely fill the space between the frames, and then it is not only impossible to wash the sugar out, but very difficult to dump the cake from the frame. One inch has been found to be the proper thickness of cake for the best work.

Fourth, the juice must be completely drained from the cylinder before the washing is started, so that the wash-water will not be contaminated with free juice. The water which fills the cylinder when the washing is stopped is sent to the excess wash-water tank to be used for the first washing of the next press. The excess wash water should not contain more than 0.6% sugar, and with proper care it will remove much of the sugar from the cake. To get along with a small amount of wash-water, keep it free from juice.

Fifth, to get even washing, the cakes must be of equal thickness on all the frames. Therefore, cloth of the same kind and age must be used on all the frames of a filter. When the cloth of one frame is ruptured, all the frames in that filter are re-dressed or else renewed with frames of even-aged dressing. The frames which have been removed with serviceable cloths are used for replacments in other filters until one size is exhausted; then another filter is completely re-dressed and so on. Partly used cloths are not removed from the frames in changing from one filter to another.

Sixth, all valves and joints on the filters must be kept in perfect repair. The gaskets between the heads and cylinders must be watched especially, because a large sugar loss may be caused by leaks at this point.

To sum up: to secure the best work from the Kelly filters, the very greatest care must be used and the following points especially observed:

(1) The air pressure must always be kept on the filters while they are being filled and washed.

(2) The air pressure must not be too high, and it must not be applied to the unprotected cake too long. Six or seven pounds pressure is about right.

(3) The cakes must not be too thick; about one inch is the best thickness.

(4) The juice must be completely drained from the cylinder before washing is begun.

(5) The cake in any filter must be of even thickness.

(6) All joints and valves must be kept in perfect repair.

The advantage of the Kelly filters compared with plate and frame presses is their use of fewer men and less cloth; their dis-

advantage is their difficulty of operation and the skilled attendance which they require.

After leaving the first carbonation filters the juice is heated, and then treated with lime kiln gas at the second carbonation. The precipitate formed here is removed in the second presses, which are used exactly like the first presses, and are subject to the same rules of operation.

At the third filter station several products are treated; thin and thick juices, high wash, and high green and melted sugar syrups and sometimes various mixtures of all of these. The operation of this station is different from the first two because of the different nature of the filtering to be done and frequently, also, because of a difference in the equipment used. The Great Western Sugar Company uses two types of filters here: plate and frame presses and Danek bag filters. The presses are similar to those used for first filtration; in some cases, they are of exactly the same type. The description already given, therefore, will suffice. The Danek filters are of two types, open and closed. In both types, the filter cloth is bag shaped, fits over a frame and collects the precipitate on its outer surfaces, as in the Kelly filter. This is about as far as the similarity goes. The frames hang vertically in the tanks, which are rectangular or box-shaped, instead of cylindrical. Very little pressure can be used with either type. Danek filters are never very efficient.

As a rule at least some of the third filters are piped to take both thin juice and thick juice; therefore great care must be used that the two juices are not mixed. With this arrangement of piping, thin juice is first filtered in a newly dressed filter until enough precipitate is deposited to fill thoroughly the pores of the cloth, so that the thick juice can be filtered clear; then, when the filter stops on thick juice, it is cut out of service and redressed. Thin juice should never be run into a filter after thick juice, because some of the impurities in the precipitate would be redissolved. When a particularly high grade of sugar is required, kieselguhr should be mixed with the thick juice and the high green, high wash and melted sugar syrups before filtration. This forms a very fine-grained porous cake in the filters which assists mechanically in filtration, and the minute particles of kieselguhr gather up some of the impurities, as a magnet gathers up iron filings.

When the cloths of the third filters become so dirty that filtration is too slow, they are removed and washed; and since they con-

tain much sugar, the first two waters in which they are washed are added to the juice, best before first carbonation.

To get the best results from third filtration these points should be observed:

(1) Use Danek filters as little as possible.

(2) Keep the thin juice separate from the thick juice and syrups.

(3) Filter the thick juice and syrups on a bed of thin juice precipitate; or better, use kieselguhr.

(4) Do not filter thin juice after thick juice or syrups, without first washing the cloths.

(5) Add the first two wash-waters to the juice, best before first carbonation.

The work which the filter stations do on the juice is purely mechanical, yet the quality of this work can effect the chemistry and mechanics of all the rest of the process.

SECTION B

It was stated in Section A of this chapter that the following conditions should exist:

(1) A minimum amount of precipitate left in the juice.

(2) A minimum amount of sugar left in the lime cake; or rather a minimum amount of sugar lost at the station.

(3) The smallest amount of wash water which will reduce the sugar in the cake to the proper point.

(4) As little labor and filter cloth as will do the work satisfactorily.

These points will be taken up and discussed in the order named. But before a clear idea of the technical side of the press station can be obtained and a clear discussion carried on, some of the terms used on the laboratory sheets must be defined. We shall take up these terms as they occur on the "Filtration Sheet" and we will attempt to explain their general meaning with a brief explanation as to their derivation.

CaO.—When limestone or calcium carbonate is burned in a lime kiln, the calcium carbonate ($CaCO_3$) is broken up into calcium oxide (CaO) and carbon dioxide gas (CO_2). Calcium oxide or quick lime is used in the Steffen process as the active medium for pre-

cipitating the sugar; and this lime and sugar precipitate is used for purifying the juices from the beets. In the non-Steffen houses it is slacked with water to make milk of lime, which is used for purifying the juices. The quantity of lime sent to the slacker and the waste matter from the slacker are weighed, the difference being the quantity of lime introduced. This figure multiplied by the percentage of CaO in the lime gives the quantity of CaO introduced. In the Steffen houses the CaO introduced is calculated by multiplying the weight of lime to the coolers by the per cent CaO in it and deducting the CaO lost in the waste water.

Tons Lime Cake.—After the net CaO introduced is determined, the total weight of lime cake is calculated by the formula:

$$\text{Lime Cake} = \frac{A \times 100}{B}$$

Where A = the tons of net CaO introduced to first and second carbonation, and B = the average percentage of CaO in the total lime cake.

Sugar Loss.—The loss of sugar in the lime cake is of two kinds and is known as "free sugar" and "combined sugar". The term "total sugar" as shown on the sheet is the sum of the free and combined sugars:

Free Sugar and Combined Sugar.—Free sugar is in the cake in the form of juice and may be removed by washing.

Combined sugar is in chemical combination with lime in the cake and is insoluble in water.

Sugar to 100 CaO.—The ratio of sugar to CaO in the lime cake is determined by the following formula:

$$\frac{100 \times \%\ \text{sugar}}{\%\ \text{CaO}} = \text{parts sugar per 100 parts CaO}$$

Water % on Cake.—This figure is determined by calculating the weight of water in tons from the volume in cubic feet, as given by the meter, and then dividing this figure by tons of cake, thus:

$$\frac{\text{Tons water} \times 100}{\text{Tons cake}} = \text{per cent water on cake.}$$

Loss of Sugar in Filter Cloth Washing.—The sugar lost in filter cloth washing is determined by calculating the filter cloth wash-water sent to the sewer in pounds, multiplying it by the per cent sugar in the water, and dividing by one hundred.

A MINIMUM AMOUNT OF PRECIPITATE LEFT IN THE JUICE

The primary work of the carbonation is to precipitate the impurities in the juice so that they may be filtered out in the first and second filters. The first carbonation of the juice is not carried to neutrality, because there are certain impurities soluble in a neutral solution which are insoluble in an alkaline solution, and the first filter station should be operated with this point constantly in mind. The second filters are not refilters for first juice. The juice leaving the first presses should be clear and sparkling and of a light yellow color. Any cloudiness shows the presence of precipitate and should be carefully avoided because the precipitate contains impurities which should have been removed. When the alkalinity is reduced in the second carbonation these impurities are re-dissolved and in this way some very harmful non-sugars, particularly lime salts, may be thrown back into solution and interfere with all the rest of the process.

A MINIMUM AMOUNT OF SUGAR LOST AT THE STATION

(1) Loss in lime cake.
(2) Loss through leaks, or unknown loss.

Loss in Lime Cake.—This loss under good conditions amounts to about 0.1% on the weight of beets. There are two controlling factors, the quantity of cake and the percentage of sugar in the cake. In the non-Steffen houses it is therefore important to keep the lime addition as low as is consistent with proper purification. In a Steffen house it is necessary to keep the lime addition as low as is consistent with a low sugar loss in the waste water.

The amount of lime cake varies from 10% on the weight of beets in a non-Steffen house to 25% on the weight of beets in a Steffen house, depending upon the amount of lime added to the first carbonation.

Assuming that 12% is a normal figure for a non-Steffen house and 18% for a Steffen house, a difference of 0.10% sugar in the

lime cake is equivalent to 240 bags of sugar for a campaign at a non-Steffen house cutting 100,000 tons of beets; 360 bags for a campaign at a Steffen house cutting 100,000 tons, and 720 bags at a Steffen house, cutting 200,000 tons. To illustrate, suppose the lime cake contains 1.1% sugar and that by using a little more care, cake with 1.0% sugar can be produced.

Twelve per cent cake on beets for 100,000 tons is equivalent to 12,000 tons of cake.

1.1% of 12,000 tons = 132 tons
1.0% of 12,000 tons = 120 tons

Difference ..... 12 tons
And 12 tons of sugar = 240 bags of sugar.

Therefore a difference of 0.1% sugar in lime cake would be equivalent to one-tenth of the above or 12 tons, or 2.4 bags of sugar per 1,000 tons of beets.

Loss Through Leaks or Unknown Loss.—Besides the sugar actually left in the lime cake due to inefficient washing, some juice may leak out of the press into the scroll. Sugar lost in this way may be estimated by a comparison of the analysis of the lime flume sample with the analysis of the sample taken directly from the filters, thus: subtract the sugar to 100 CaO in the cake from the sugar to 100 CaO in the lime flume and multiply this difference by the quantity of CaO in the lime cake, stated as a weight or as a percentage of the weight of lime cake, beets or sugar, according to the form of statement desired. The Great Western Sugar Company considers this loss unaccountable in estimating extraction.

The average lime cake losses for the 1919-20 campaign at one large Steffen house were as follows:

Sugar to 100 CaO in the lime flume.....6.2
Sugar to 100 CaO in the lime cake.....4.3

Difference 1.9

or

Sugar in lime flume, % on beets.....0.22
Sugar in lime cake, % on beets.....0.15

Difference 0.07

The difference should represent the loss from leakage, etc., and it shows that over 30% of the losses on the filter station could have been avoided if all leaks had been stopped.

There are various other places where this unknown loss may occur. It is of primary importance to first of all make sure that accurate average samples of all lime cake be obtained. If there is still a difference between the cake and flume sample a careful search should be made for any losses which may occur through defective valves and gaskets, leaky juice troughs or juice pans, frame leaks, and so on.

THE SMALLEST AMOUNT OF WASH WATER THAT WILL REDUCE THE SUGAR IN THE CAKE TO THE PROPER POINT

All of the water used for washing the sugar out of the cake has to be evaporated at the expense of coal and sometimes at the expense of capacity if the size of the evaporators is relatively small. The amount of water varies from 80% to 180% of the weight of the cake, according to the efficiency of the station and the care taken in its operation. A difference in the amount of water used for washing cake, corresponding to 10% of the weight of the cake, is equivalent to 1,200 tons of water to be evaporated or 40 tons of coal to be burned per 100,000 tons of beets at a non-Steffen house, and 1,800 tons of water or 60 tons of coal at a Steffen house. It is therefore important that the amount of wash water used be carefully watched and that it be kept at a minimum.

Great care should be taken, however, not to save wash water at the expense of sugar. As shown in our previous calculations, a reduction of 0.10% of sugar in lime cake means a saving of 2.4 bags of sugar per 1,000 tons of beets. This means 2.9 bags per day at a 1,200-ton non-Steffen factory, which is approximately equivalent in value to 6 tons of coal, and this coal will evaporate 150 tons of water or 104% on cake.

For a plate and frame press the amount of water used varies somewhat, depending on the nature of the cake, but more on the extent to which the sugar is washed out. The frames should be well filled and the press should be washed slowly to avoid channeling. One of the most important points is to keep the frames clean so that all the water introduced into the press passes through the cake. The wash water should be as hot as possible, at least 90° C.

In the case of Kelly filters, the watching of the end point is of even more importance than with the plate and frame press, the rate of washing being so much greater. It is also important to have cake of a certain even thickness; one inch usually gives the best results in washing.

The second presses are operated in general like the first presses and the same considerations of good filtration, low losses and low per cent of wash water apply.

In general the third press station gives very little trouble; nevertheless, it should receive its proper share of attention. There are certain conditions of operation which must be maintained if sugar of the highest grade is to be produced.

It is quite common for a number of the third filters to be cross connected to both thick and thin juice and in some cases to thin juice and high wash syrup. The reason for this is two-fold; it is thus possible to change the presses from one service to another as occasion demands, and theoretically, at least, it is possible to secure a better filtration of thick juice by first closing the pores of the cloth by filtering thin juice. The mat of thin juice precipitate is supposed to retain some of the fine particles of impurities in the thick juice which the cloth alone would not stop. Thin juice should never be run through a filter which has been used for thick juice until the cloths are washed; impurities which have been precipitated by the concentration of the liquor to thick juice will be re-dissolved by the thin juice.

It sometimes happens that on account of bad beets or defects in the preceding part of the process the thin juice is burdened with an excessive amount of lime salts. Besides other detrimental effects, this often produces a greatly increased amount of precipitation in the thick juice blowups. Thus it is sometimes impossible to wash cloths and dress filters fast enough to keep the house going at its full capacity. The source of the lime salts must be located at once. The trouble often comes from leaky valves around the second or third carbonation; sometimes it is caused by decayed or fermented beets. In the case of bad beets it is often necessary to add soda to the juice in order to reduce the lime salts. Soda ash is usually added at the battery, but may be introduced anywhere before third saturation.

AS LITTLE LABOR AND FILTER CLOTH AS WILL DO THE WORK SATISFACTORILY

Of course the various filtration stations should be operated as economically as possible. The filter cloths should be worn out; but

no economy is accomplished by using leaky cloths. It is often possible to patch the third press cloths or make one good cloth out of two defective ones with little expense and without hurting the filtering efficiency of the station. Filter cloth is expensive and every effort should be made to use as little as possible. Efficient organization and effective co-operation can do much to reduce the cost of labor.

PROBLEMS

(1) What would be the saving in bags of sugar for a hundred days of campaign at a 2,200-ton house if the sugar in lime cake is reduced from .9% to .7%, the lime cake being 18% on beets? What would be the saving in coal if the wash water is reduced from 180% to 120%?

(2) What would the sugar loss be under the following conditions? Express the loss as per cent on beets.

Tons beets sliced	1,000
CaO introduced, % on beets	2.5
% CaO in lime cake	20.0
% Sugar in lime cake	0.8

CHAPTER NO. VI

EVAPORATORS AND STEAM ECONOMY

SECTION A

In previous lectures we have studied two of the main processes in the manufacture of beet sugar, i. e. (1) the extraction of the sugar from the beet, and (2) the purification of the extracted juice. Now we come to the third process, "the evaporation of the juice to the point where crystallization takes place." This evaporation is carried on in two stages, the first part of the water being removed in what are known as multiple effect evaporators, while the last part is taken out in the vacuum pans.

The juice, after leaving the third presses, is pumped through a set of heaters to the evaporators, where the first and larger part of the water is removed. The usual set of evaporators used by The Great Western Sugar Company consists of five bodies in tandem which together are known as quintuple evaporators. If four tandem bodies are used, the evaporators are called quadruple evaporators, while three tandem bodies are called triple evaporators. The horizontal tube type of evaporator is used at all factories except Scottsbluff, where vertical tube evaporators are used.

The horizontal type of evaporator consists of a body made of cast iron or steel approximately 11 feet high, 10 feet wide and 13 feet long. At each end of the body is a projection about 18 inches wide and 40 inches high, which forms a steam chest. Brass tubes ranging from ¾ inch to 1 inch in diameter project from one steam chest to the other and are separated from the juice chamber by a tube sheet. The juice is introduced into the juice chamber and completely surrounds the outside of the tubes, while the steam enters the steam-chest, passes through the inside of the tubes, and is condensed. The heat given up by this condensation is transmitted through the tubes to the juice, where it causes an equal amount of water to be evaporated from the juice. Plate No. 7 shows a sketch of a single body or effect of a set of evaporators.

A quintuple set of evaporators consists of five bodies like the one above described, piped together in such a manner that the water evaporated from the first body, while still in the form of vapor, passes into the steam-chest of the second body; the vapor from the second body passes into the steam-chest of the third body; the vapor from the third body enters the steam-chest of the fourth

Plate No. 7.

EVAPORATOR

NOTE
WHILE GAUGE SHOWS JUICE LEVEL BELOW TOP OF TUBES, THIS DOES NOT MEAN THAT JUICE IS BELOW THE TOP OF TUBES, AS THE JUICE IS FOAMING AND AN UNSTEADY MASS AND KEEPS THE LEVEL ABOVE TUBES.

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body; the vapor from the fourth body goes into the steam-chest of the fifth body; and the vapor from the fifth body goes to a condenser. The juice enters the first body where a portion of the water is removed, passes from there to the second body and so on until it reaches the fifth body, from which it is pumped to the blow-ups. Plate No. 8 shows in more or less detail the manner in which these bodies are connected together.

Let us now analyze what takes place during their operation. Consider that the evaporators are all filled with juice at the boiling point, that steam is turned into the steam-chest of the first body and water is turned into the condenser. The steam in the first body steam-chest begins to condense and in so doing gives up its latent heat which evaporates from the juice a quantity of water equal to the weight of the steam condensed. The vapor thus evaporated from the first body enters the steam-chamber of the second body, gives up its latent heat and evaporates from the juice in the second body water equal to its weight. This process is continued; the second vapor evaporates water from the third body; the third vapor evaporates water from the fourth body; and the fourth vapor evaporates water from the fifth body, while the vapor from the fifth body is led to the condenser. The condensing of the vapor in the steam-chest ahead creates a partial vacuum in the body from which it is taken and after a set of evaporators is operating well the pressures may range approximately as follows: First body, seven pounds above atmospheric pressure; second body, two pounds above; third body, three inches vacuum; fourth body, fourteen inches vacuum; fifth body, twenty-two inches vacuum.

Thus it might be said that each body is in effect a condenser for the preceding body, so that practically all of the heat introduced in the first body is used again in each of the following bodies. The last body delivers all of its vapor to the condenser, where the utilization of heat for useful work ends.

One pound of steam admitted into the steam-chamber of the first body evaporates five pounds of water in a quintuple evaporator. In the same way, one pound of steam evaporates two pounds of water in a double effect evaporator, three pounds in a triple evaporator, and four pounds in a quadruple effect evaporator. Now when Colorado lignite coal is burned in a well operated boiler house, one pound of coal makes six pounds of steam; and since one pound of steam evaporates five pounds of water in a quintuple effect evaporator we can see that by its use one pound of coal evaporates thirty pounds of water from the juice.

The evaporators are one of the most interesting and important stations in a sugar factory and the amount of work that they perform each day is tremendous. In a factory slicing 1,200 tons of beets a day, the evaporators must evaporate 1,400 tons of water each 24 hours and it is thus apparent that anything which delays the evaporators will sooner or later delay the whole process.

The evaporators should be operated with two points in view: (1) They should be operated at such a rate that they never retard the factory, and that means operation of the evaporators at their greatest possible capacity; and (2) they should be operated so as to make the necessary evaporation with the use of a minimum quantity of steam.

The capacity of a set of evaporators depends upon several things:

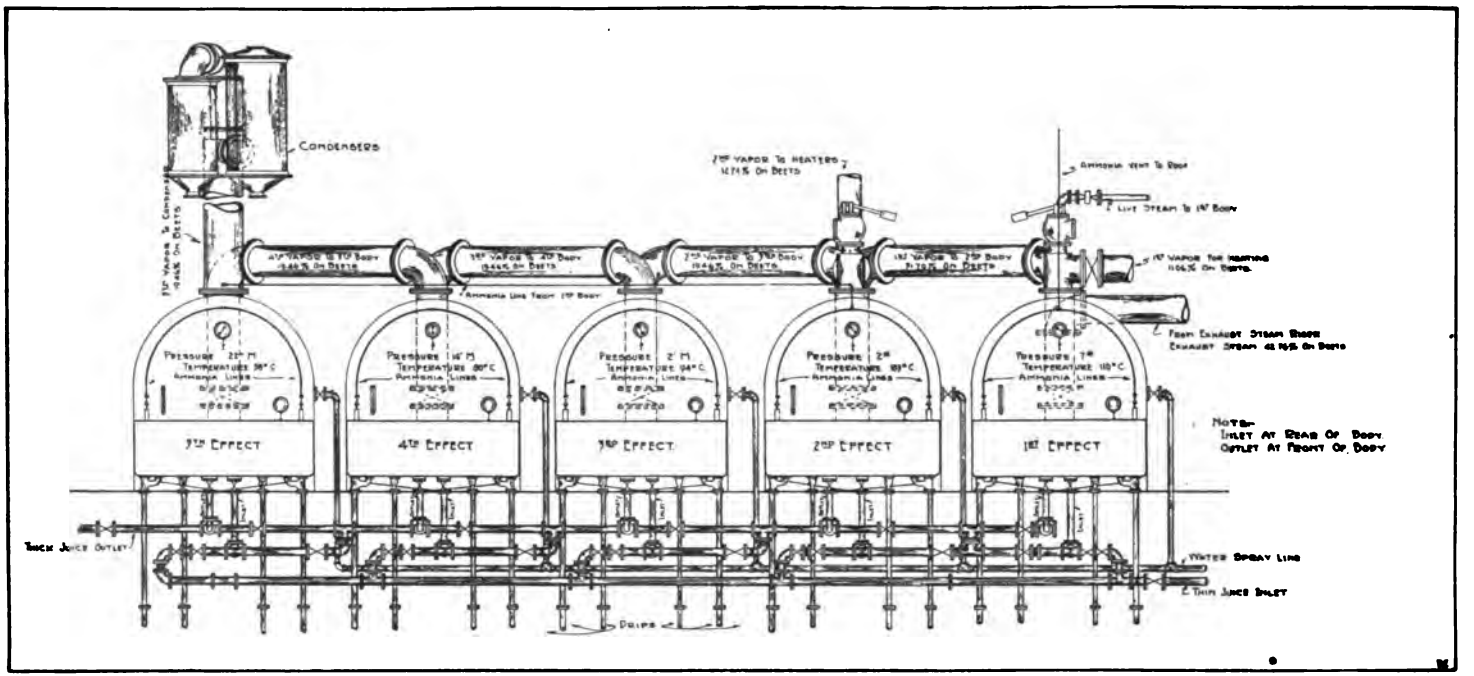
(1) The tubes must always be kept clean or heat cannot be transmitted through them rapidly and the capacity will be reduced. By watching the temperature differences between the different bodies it is possible to tell whether or not the tubes of any body are becoming dirty. As an example, suppose the usual temperature difference between the third and fourth body is 14° C.; any increase in this temperature difference is a sign that the tubes in the fourth body are dirty. To keep the evaporators clean in a sugar factory it is often necessary to "boil them out," and this is usually done by boiling in them first a solution of soda ash and then following with a solution of acid. The boiling out is accomplished without shutting down the system; the juice being by-passed the body to be boiled out. Extreme care must be taken when soda or acid is introduced to see that all valves are properly set, or else acid or soda will mix with the juice and this may cause a large sugar loss.

(2) The condensed water must be removed practically as fast as it is formed or the capacity of the evaporators will be reduced. For this reason the operator should always watch the gauge on the steam-chest to be sure that water is not accumulating in the steam-chambers.

(3) The air and other non-condensable gases must be removed from the tops of the steam-chests, and, to accomplish this, certain pipes called ammonia lines are provided. The proper manipulation of the ammonia lines is extremely important, since if the valves are not opened sufficiently wide the gas collects in the tubes and the evaporators are slowed up; while if opened too wide a large

QUINTUPLE SET OF EVAPORATORS

Plate No. 8.



No. 820

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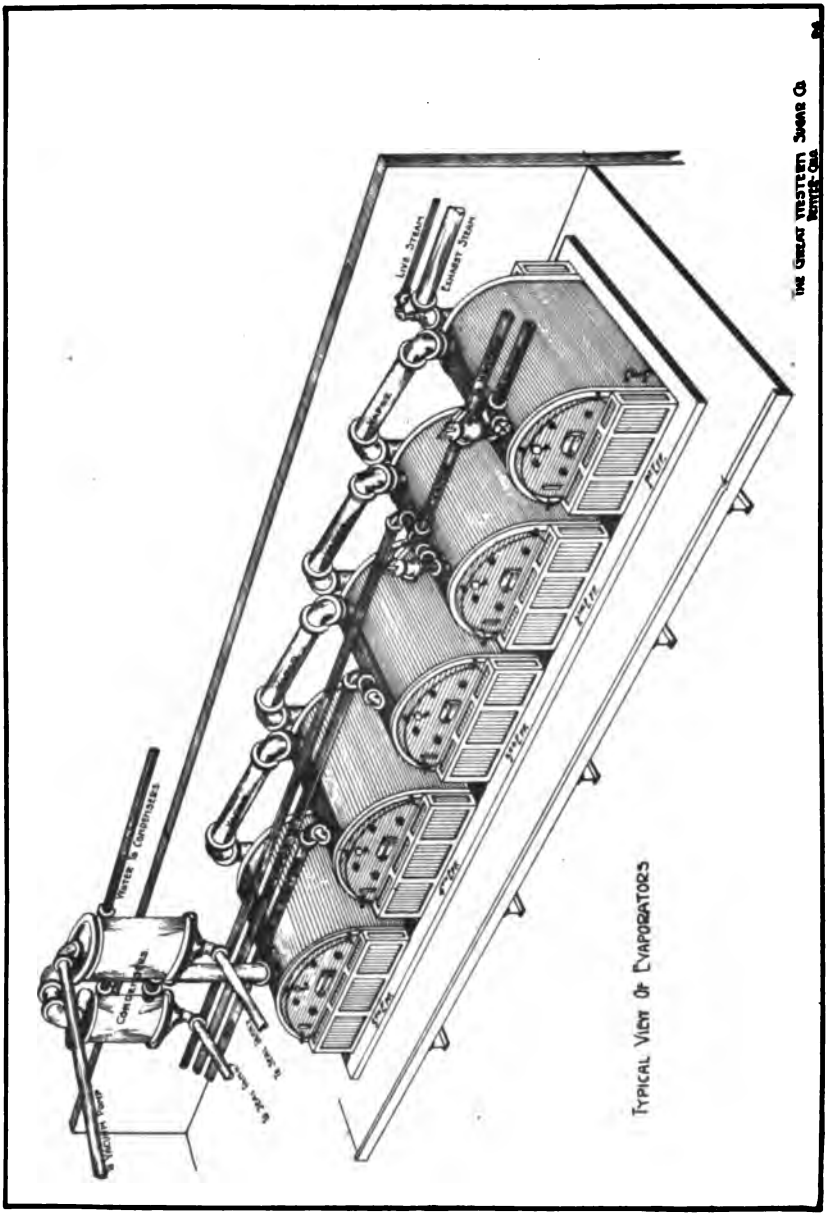
Plate No. 9.


THE GREAT WESTERN SUGAR CO.
DENVER, COLO.
LIVE STEAM
EXHAUST STEAM
WATER & CONDENSER
TYPICAL VIEW OF EVAPORATORS

UNIV. OF
CALIFORNIA

quantity of vapor passes into the vapor chamber of the next body without having done any evaporating and thus a certain amount of heat is lost.

(4) The height of the juice in the body has a large effect on the capacity of the evaporators and experiments have shown that for maximum capacity the level of the juice should be carried at such a height that, when boiling, the top tubes will be just covered.

(5) An increase in the viscosity of the juice decreases the capacity of the evaporators, and the addition of melted sugar at second carbonation instead of the blow-ups, although sometimes advisable for other reasons, raises the density of the juice, increases its viscosity, and decreases the capacity of the evaporators.

(6) The difference between the temperature of the steam entering the first body and the vapor leaving the last body has a very great effect on the capacity of the evaporators. An increase in this temperature difference can be attained in two ways, either by increasing the pressure of the entering steam and consequently its temperature, or by increasing the vacuum in the last body so that the temperature of the juice will be lowered. Since the vacuum on the last body is usually as high as it is possible to obtain, the usual method of increasing the capacity of the evaporators is to increase the pressure of the steam entering the steam-chest of the first body.

The factors of evaporator operation which economize steam may be summed up as follows:

(1) The use, wherever possible, of the vapors instead of live steam for heating purposes.

(2) The concentration of the thick juice in the evaporators to a high density (68° to 70° Brix). In the evaporators one pound of steam evaporates five pounds of water, while any water left in the thick juice when it leaves the evaporators has to be removed in the vacuum pans by single effect evaporation where one pound of steam evaporates only one pound of water.

QUESTIONS FOR DISCUSSION

(1) Name three things that may cause slow boiling or reduced evaporator capacity.

(2) If the temperatures of the different bodies are usually

	Temperature	Temperature Difference
First body	110° C.	.....
Second body	103° C.	7° C.
Third body	94° C.	9° C.
Fourth body	80° C.	14° C.
Fifth body	60° C.	20° C.

But because of dirty tubes they change to

First body	110° C.	.....
Second body	103° C.	7° C.
Third body	95° C.	8° C.
Fourth body	77° C.	18° C.
Fifth body	60° C.	17° C.

Which body would you say is getting dirty?

(3) Why should the vacuum in the last body be as high as possible?

(4) In normal running how is the capacity of the evaporators increased?

(5) What is the best juice level to obtain the maximum capacity in the evaporators?

(6) Why should the valves on ammonia lines be somewhat open?

(7) What happens if these valves are open too wide?

SECTION B

The manner is which the evaporation is conducted determines to a large extent the entire steam economy of the factory. A thorough understanding of the underlying principles governing evaporation in general is therefore quite essential to successful sugar factory operation, and since this understanding cannot be properly grasped without a knowledge of certain fundamentals we will define and discuss some of them before taking up the actual operation of the evaporators.

Evaporation of water is brought about by the addition of heat to the water in sufficient quantity to cause it to change from the liquid state (water) into the gaseous state (steam or vapor). To control this, one of the first things that must be secured is some measurement of heat itself, so that we may know definitely what quantity of heat is being used. An understanding of the measurement of temperature, therefore, is necessary in order to comprehend the use of heat.

MEASUREMENT OF TEMPERATURE

For the measurement of temperature two types of thermometers are in common use; namely, the Centigrade and the Fahrenheit. In making the scale of the centigrade thermometer, the freezing point of water (at sea level) is taken as zero (0° C.) and boiling point of water (at sea level) is taken as one hundred (100° C.). These points are marked on the scale and the entire distance between them is divided into 100 equal parts called "degrees" (° C.); thus we can say that one degree centigrade (1° C.) represents 1/100 of the total change in temperature between freezing and boiling water.

In making the scale of the Fahrenheit thermometer the difference between the freezing point and the boiling point of water at sea level is taken as one hundred and eighty degrees. Using this scale, Fahrenheit was able to obtain a temperature thirty-two degrees below the freezing point of water. He considered this point the lowest possible temperature and called it zero. The freezing point of water is thus thirty-two degrees above zero (32° F.), the boiling point (at sea level) is thirty-two plus one hundred and eighty degrees or two hundred and twelve degrees Fahrenheit (212° F.), and one degree (1° F.) represents 1/180 of the total change in temperature between freezing and boiling water.

From this it is seen that one hundred Centigrade degrees (100° C.) are equal to one hundred and eighty Fahrenheit degrees (180° F.), or that one centigrade degree equals one and eight-tenths Fahrenheit degrees.

MEASURE OF UNIT OF HEAT

For the measurement of the quantity of heat for engineering calculations two units are in common use; namely, the British thermal unit, usually written B. t. u., which is used in English-speaking countries, and the large Calorie, usually abbreviated to C., which is the European unit.

The British thermal unit or B. t. u. may be defined as that quantity of heat which is required to raise the temperature of one pound of water through one degree Fahrenheit. Now from this can be determined the quantity of heat needed to raise any quantity of water through any range of temperature. As an example, let us consider that we have 100 pounds of water which we wish to raise from 40° F. to 50° F., or a total of 10 degrees. From the definition it is seen that 1 B. t. u. is the quantity of heat required to raise the temperature of one pound of water 1 degree Fahren-

heit; therefore, the quantity of heat necessary to raise 100 pounds of water 1 degree Fahrenheit would be 100 × 1 or 100 B. t. u., and the quantity of heat needed to raise the temperature of 100 pounds of water 10 degrees Fahrenheit would be 100 × 1 × 10 or 1,000 B. t. u. We can therefore state that the heat, expressed in B. t. u's., needed to raise any quantity of water through any range of temperature is equal to the weight of water in pounds multiplied by the number of degrees Fahrenheit that the temperature of the water is to be raised.

The large Calorie, as stated above, is the engineering heat unit used in European countries and may be defined as that quantity of heat which is required to raise the temperature of one kilogram (2.2 pounds) of water one degree centigrade. The heat, expressed in Calories, required to raise any quantity of water through any range of temperature can be calculated in a manner similar to that given for British thermal units; that is, it is equal to the weight of water in kilograms multiplied by the number of degrees centigrade that the temperature of the water is raised.

It should be recognized that the B. t. u. or the Calorie represents a measure of a quantity of heat just as the pound represents a measure of a quantity of weight or the gallon represents a measure of a quantity of volume.

In studying heat two general divisions are made, one of which is called sensible heat and the other latent heat.

SENSIBLE HEAT

Sensible heat is the heat which a body has because of its temperature, and any change in the temperature of the body changes its sensible heat. Thus, 100 pounds of water at a temperature of 50° F. has a certain sensible heat, and if the same quantity of water is raised to a temperature of 60° F. it has a greater sensible heat, amounting to 100 × 10 or 1,000 B. t. u., and this quantity of additional heat must have been supplied to the water before its temperature can be raised through ten degrees. In the same way, if we consider freezing water at 32° F. as a standard or the zero point, we should say that the sensible heat of 100 pounds of water at 50° F. is 100 × (50 — 32) or 100 × 18 = 1,800 B. t. u.; while the sensible heat of 100 pounds of water at 60° F. is 100 × (60 — 32) or 100 × 28 = 2,800 B. t. u., and the difference in the sensible heat of the 100 pounds of water at the two different temperatures is 2,800 — 1,800 = 1,000 B. t. u.

LATENT HEAT

Some substances exist in several different physical states. For example, water may exist as a solid in the form of ice; as a liquid in the form of water; or as a gas in the form of steam or vapor. When ice is melted, the water changes from a solid into a liquid, and to convert the water from ice at 32° F. or 0° C. into water at 32° F. or 0° C. a certain amount of heat must be added. This added heat is called the *latent heat of fusion.* It must be noticed that the ice and water are of the same temperature, or in other words, there has been in this case no change in the sensible heat; all the heat added has been used up in converting the ice into water; that is, in changing its physical condition. In the same way, if we have water at the boiling point (212° F. or 100° C.) we must add a certain amount of heat to change the water from a liquid at a temperature of 212° F. or 100° C. into steam or vapor at the same temperature and this heat is called the *latent heat of evaporation.* Here again it is seen that the water and the steam are of the same temperature, therefore the sensible heat must be the same as before, and what heat was added must have been used up in changing the water from a liquid into a gaseous form.

Latent heat can therefore be defined as the heat which a body has because of its physical condition.

Suppose one pound of boiling water is contained in a closed can connected to a rubber bag which is air tight but can freely expand. Now let heat be added to the water until it is all evaporated. The one pound of material remains within the apparatus after the evaporation, but it is in the form of steam instead of water. If the heat used has been accurately measured, and just enough has been used to evaporate the water, it will be found that it required 970.4 B. t. u. of heat to change the one pound of water from a liquid into a gas, or in other words *"the latent heat of evaporation for water is 970.4 B. t. u."*

Now if this apparatus containing one pound of steam is plunged into a known quantity of water, the steam will be condensed into one pound of water and will give off to the surrounding water an amount of heat equal to 970.4 B. t. u. In other words, a pound of steam, upon condensing to water, gives up the same quantity of heat that was required to change the one pound of water to steam.

This is what takes place in ordinary evaporation in a sugar house. Steam is introduced on the inside of an evaporator tube or

a pan coil, and the tube or coil is surrounded by juice; the steam condenses and gives up its latent heat, the heat is transmitted through the tube or coil to the juice and the same amount of water is evaporated from the juice as was condensed from the steam.

Making an experiment similar to this, but using one kilogram (2.2 pounds) of water instead of one pound, and measuring the heat in terms of Calories, we shall find that it requires 537 Calories of heat to convert the one kilogram of water from water at 100° C. to steam at 100° C.; that is, the *latent heat of evaporation for water is 537 Calories.*

This discussion has brought out how heat may be measured and how it may be divided into two classes, sensible and latent, but there is still another point of general interest which should be considered before we go into the actual discussion of the evaporators; namely, the *temperature at which a liquid boils depends upon the pressure.* The term "atmospheric pressure" means the pressure exerted upon a body out in the open air; it is caused by the weight of the column of air above the body. It amounts to 14.7 pounds per square inch at sea level, but at Denver it amounts to about 12.8 pounds per square inch; and since the temperature of the boiling point decreases as the pressure decreases, water which boils at sea level at 212° F. or 100° C. will boil in Denver at about 204.0° F. or 95.2° C. We can therefore lower the boiling point of a liquid at any time by decreasing the pressure over the liquid, or as we commonly state it, by putting a vacuum over the liquid. Below is a table showing the boiling point of water for different degrees of partial vacuum:

	Boiling Point of Water			
	Sea Level		Denver	
Inches of Vacuum	°F.	°C.	°F.	°C.
0	212	100	203	95.2
5	203	95	193	89.5
10	192	89	180	82.2
15	178	81	163	73.0
20	161	72	133	56.0

It is now of interest to see how these principles can be applied to the operation of the evaporators in a sugar factory.

We have shown in Section A that the steam put into the first body evaporates water from the juice in the first body equal to the weight of steam condensed; that the vapor from the first body evaporates a like amount of water from the second body, etc., etc.

If 100 pounds of steam had been added to the steam chest of the first body it would have evaporated:

In the first body	100	pounds of water
In the second body	100	pounds of water
In the third body	100	pounds of water
In the fourth body	100	pounds of water
In the fifth body	100	pounds of water
In the five bodies	500	pounds of water

This table shows that in a quintuple (five effect) evaporator, each pound of steam evaporates five pounds of water; in a double effect evaporator it evaporates two pounds of water; in a triple effect, three pounds; and in a quadruple effect, four pounds.

The one pound of steam entering the steam chest of the first body contains 970.4 B. t. u. of latent heat because of the fact it is *steam.* Upon condensation this latent heat converts one pound of water into vapor which likewise contains 970.4 B. t. u. of latent heat because it is *vapor* or *steam.* Now the one pound of first vapor with its 970.4 B. t. u. of latent heat is condensed in the steam-chest of the second body, the latent heat is liberated and one pound of water is evaporated from the juice on the other side of the tube-wall, forming one pound of second vapor with its latent heat. In the same way, the latent heat in the second vapor evaporates one pound of water from the juice in the third body, the latent heat in the third vapor evaporates one pound of water from the juice in the fourth body and the latent heat in the fourth vapor evaporates one pound of water from the juice in the fifth body. By a series of condensing and evaporating operations, the *latent heat* of evaporation in the original steam is transferred from one batch of juice to another and used over and over again.

The amount of water that must be evaporated in a set of evaporators at one of our factories is immense. We have introduced the following calculation to show the amount of juice handled by a set of evaporators and the quantity of water removed.

A factory slices 1,200 tons of beets per 24 hours; the beets contain 16.00% sugar, the pulp contains .20% sugar, the pulp water contains .10% and the sugar loss in lime cake is .05% on beets. The purity of the evaporator thin juice is 90.0, its Brix 12.0° and the Brix of the Thick Juice 65.0°. How much thin juice must the evaporators handle and how much water removed in the evaporators?

Let A = Tons beets cut ..... = 1,200
M = % Sugar in beets ..... = 16.00
B = % Sugar in pulp ..... = .20
C = % Sugar in pulp water ..... = .10
I = Sugar lost in lime cake, % on beets = .05

$$N = \text{Tons sugar in beets} = \frac{A \times M}{100} = \frac{1{,}200 \times 16}{100} = 192.00.$$

$$D = \text{Tons sugar lost in pulp} = \frac{A \times B}{100} = \frac{1{,}200 \times .20}{100} = 2.40.$$

$$E = \text{Tons sugar lost in pulp water} = \frac{A \times C}{100} = \frac{1{,}200 \times .10}{100} = 1.20.$$

$$Y = \text{Tons sugar lost in lime cake} = \frac{A \times I}{100} = \frac{1{,}200 \times .05}{100} = .60.$$

K = Tons sugar in thin juice = N — D — E — Y = 187.80.
P = Purity thin juice = 90.0.

$$Q = \text{Tons of Dry Substance in thin juice} = \frac{K}{P} \times 100 = \frac{187.80}{90} \times 100 = 208.66.$$

H = Brix of thin juice = 12.0.

$$X = \text{Tons of thin juice} = \frac{Q \times 100}{H} = \frac{208.66 \times 100}{12} = 1{,}738.88.$$

G = Brix of thick juice = 65.0.

$$J = \text{Tons of thick juice} = \frac{Q \times 100}{G} = \frac{208.66 \times 100}{65} = 321.02.$$

Z = Tons of water evaporated = X — J = 1,738.88 — 321.02 = 1,417.86.

For each 1,200 tons of beets over 1,400 tons of water must be evaporated in the evaporators.

The exhaust steam discharged from the engines is still in the form of steam and still retains its latent heat; it is, therefore, capable of evaporating water. The steam used in the engines is usually at about 125 pounds gauge pressure while the exhaust steam leaving the engines is kept at a pressure of from 8 to 12 pounds; and since the total heat (sensible and latent) of a pound of steam at 125 pounds pressure is 1,192 B. t. u., while the total heat of a pound of steam at 8 pounds pressure is 1,162 B. t. u., one pound of exhaust steam is worth almost as much for evaporating purposes as one pound of live steam. Thus sugar factories get practically as much evaporation from one pound of steam after it has passed through the engines and delivered up its power as they

could from one pound of steam taken directly from the boiler house. All of the exhaust steam is collected into a central system, from which it is drawn for evaporating and heating. In the older factories there were a great many small steam units, such as pumps, etc., and since these were inefficient, a large quantity of exhaust steam was made. Often so much was produced that it could not all be used by the evaporators and the excess exhaust steam was discharged into the atmosphere, or we usually say "blown to the roof". In our present factories, however, larger and more efficient steam units are used and there is not enough exhaust for the evaporators. This deficiency must be made up by the addition of live steam to the exhaust system through an automatic regulating valve known as the Locke Regulator. The Locke valve is set for a definite pressure in the exhaust system, at say 12 pounds, and only enough live steam is admitted to maintain the exhaust system at that pressure. There is also a Locke regulator on the exhaust line to the roof in order that the exhaust steam may blow to the roof if the pressure becomes too great. Care should be taken to see that the Locke valve to the roof is set at a higher pressure than the Locke valve admitting live steam to the exhaust system, so that in case of a reduced consumption of steam in the evaporators the live steam valve will close before the exhaust blows to the roof.

Because the evaporators are so important to the sugar factory, it is essential that we should understand the factors which influence their capacity.

TRANSMISSION OF HEAT

The steam or vapor used for the evaporating is separated from the juice by means of some sort of metal wall through which the heat contained in the steam or vapor must be transmitted to the juice. Our company has chosen brass evaporator tubes for several reasons; first, the metal is hard and durable; second, it conducts heat more rapidly than any other common metal except copper; third, it is quite insoluble in dilute acid solutions and therefore allows boiling out with acid to remove the scale.

In studying the transmission of heat by different metals and under different conditions, use is made of a certain ratio known as the "coefficient of transmission of heat". In the metric system it is the number of Calories which pass in one hour from a warmer to a colder fluid through one square meter of heating surface when the difference in temperature between the warmer and the colder fluids is 1° C. In the English system it is the number of B. t. u. which pass in one hour from a warmer to a colder fluid through

one square foot of heating surface when the difference between the warmer and colder fluids is 1° F. The metric system is in general use in evaporator calculations and any figures quoted will refer to that standard.

With any given set of evaporators, other things being equal, the capacity or quantity of water than can be evaporated with them depends very largely on how rapidly the heat can be transmitted through the tubes. Anything which affects the "coefficient of transmission of heat" affects the capacity of the evaporators. Factors which materially affect the rapidity of the heat transferrence and consequently are of importance in connection with the capacity of the evaporators are:

Velocity of vapors,
Composition of the tubes,
Cleanliness of surface,
Removal of condensed water,
Removal of air and non-condensable gases,
Height of juice in body,
Viscosity of juice,
Temperature difference.

Velocity of Vapors.—The greater the valocity with which the steam passes over the heating surface, the faster will be the transmission of heat. It is for this reason that the heating surface in our horizontal effects is divided up into passes so proportioned as to maintain high velocity in the steam as its volume is reduced by condensation.

Composition of the Tubes.—Many experiments have been made with various metals. If iron is considered as a standard with a value of 100, the other metals would range as follows: Silver, 830; Copper, 610; Brass, 200. Brass is chosen rather than copper because of its greater durability.

Cleanliness of Surface.—Scales or incrustations are very poor conductors of heat. If the tubes become covered with a scale their conductivity is greatly reduced and the capacity of the evaporators is lessened. There are certain salts of calcium called lime salts, which are soluble in dilute sugar solutions, but insoluble in more concentrated solutions. As the juice thickens in the evaporators, they deposit on the tubes, forming a resistant scale. The scale is sometimes caused, or at least increased, by the settling of suspended material on the tubes. The rapid formation of scale from either cause can usually be avoided by the proper treatment of the juice

before it enters the evaporators. The scale is usually of such nature that acid alone will not dissolve it and the usual procedure is to boil first with a solution of soda ash and caustic soda, which changes the nature of the scale so that acid will attack it and then finish with acid. The boiling out is accomplished without shutting down the evaporators. The juice is by-passed the body which is to be cleaned and the body emptied. The soda and acid solutions are then introduced successively and boiled.

It is very important that the tubes be kept clean if the capacity is to be maintained.

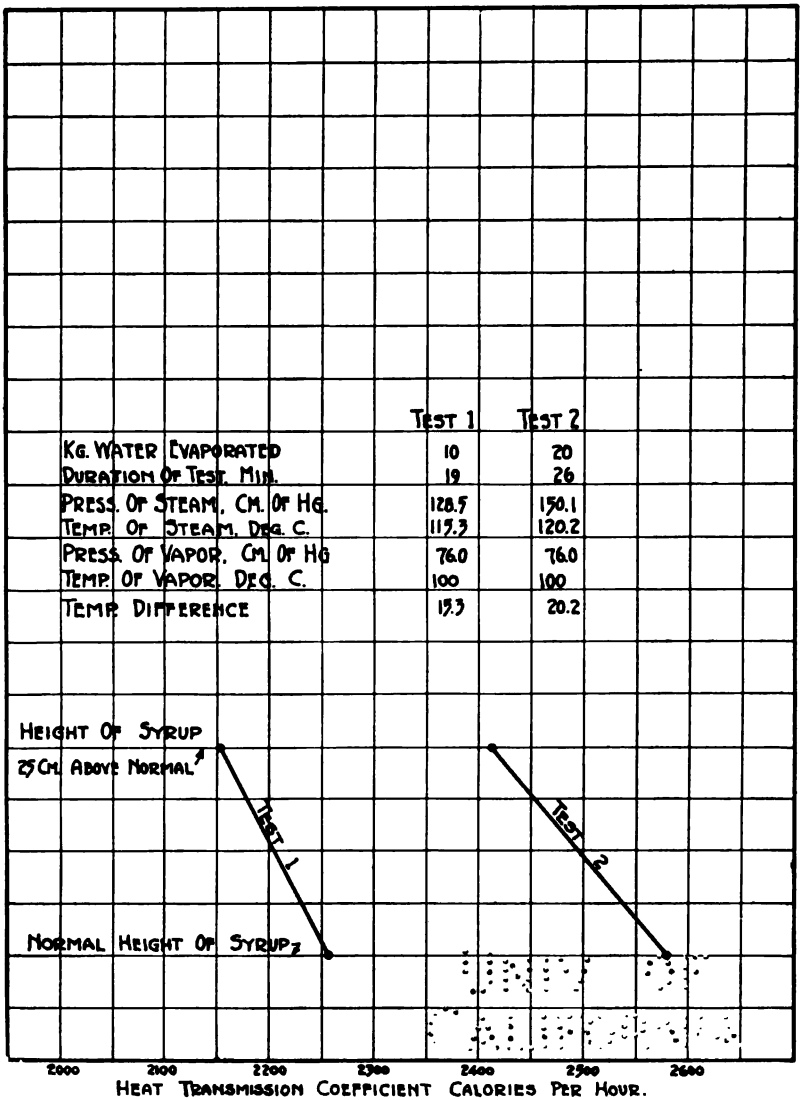
Removal of Condensed Water.—Water is a poor conductor of heat and the water which is condensed from the vapor or steam must be removed practically as rapidly as it is formed. To accomplish this in horizontal evaporators the tubes are slightly inclined and the water drains to the steam-chests from which it is removed by pumps or leg-pipes. The condensed water from the evaporators, pans, heaters and traps is quite pure (except for some ammonia), is fairly hot, and is used for various services where hot, pure water is needed, such as boiler feed and press wash. As a general rule the condensed water from the second, third and fourth effects of the evaporators, from the pan and other steam-traps together, make up the boiler water; while the condensed water from the first effect (because it contains some oil from the engines which would hurt the boilers), from the fifth effect and from the heaters goes to the press wash system. There are generally overflows from the boiler feed tank to the press wash tank and from the press wash tank to the battery supply tank.

The water from the first and second bodies, because of the pressure that exists in the steam-chambers, is passed through steam-traps and from the traps it flows by gravity to the proper tank; while the water from the third, fourth and fifth bodies, if the receiving tanks are located at a sufficiently low elevation to provide a leg sufficient to overcome the vacuum, flows directly by gravity to the proper receiving tank. In some cases, however, this tank cannot be located at a sufficiently low level and it is necessary to remove the water from the fifth body by means of a pump. Guage glasses are usually provided in the steam-chests to show whether there is any water in them. They should be watched carefully to see that the water is being removed as rapidly as it is formed, for if any of the tubes are full of water they are useless as far as heat transmission goes.

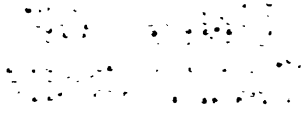
Removal of Air and Non-Condensable Gases.—The beet juices contain certain compounds of nitrogen which upon treatment with lime break up into ammonia, and although a large portion of this ammonia is formed and removed before the juice reaches the evaporators, a certain amount of it is retained until the juice is subjected to the hard boiling in the evaporators, when it goes off with the vapors from the different bodies. This ammonia and the air which leaks into these bodies under vacuum occupies a considerable volume and unless removed would soon fill up the tubes and prevent the steam from entering them and discharging its heat. To overcome this difficulty arrangements are made to remove these gases by means of a system of ammonia pipes. The ammonia pipes are generally 1½ inch in size, and are inserted into the top of the steam-chest on the front end of the evaporators so that they do not project below the top of the chest, otherwise an air or gas pocket might exist at the top of the steam-chest. The ammonia pipes from the steam-chests of the first, third, fourth and fifth bodies usually discharge into the vapor chamber of the same body. The line from the steam-chest of the second body is connected directly to the vapor chamber over the fifth body or to the condenser because most of the ammonia is liberated in the first body. A vacuum pump connected to the condenser finally removes the ammonia and air from the fifth vapor. The heaters are also provided with ammonia lines and these are usually connected to the vapor over the third body. The proper manipulation of the ammonia lines is extremely important, since if the valves are not opened sufficiently wide, the gas collects in the tubes, the heat transmission is retarded, and the capacity of the evaporators is lessened; while if opened too wide a large quantity of steam passes into the vapor of the next body without having done any evaporating and heat is lost. This is particularly true of the ammonia line from the second body steam-chest, which enters the vapor over the fifth body.

Height of Juice in the Body.—The rapidity of heat transferrence depends to a large extent upon the speed with which the bubbles of vapor or steam leave the heating surfaces and get out of the juice; and this is affected by the height of the juice in the body. A bubble of steam formed on one of the lower tubes must force itself through the column of juice above it; the less the height of the juice, the faster the bubble will leave the surface of the tube, the sooner another bubble will form, the greater will be the heat transmission and the more juice the evaporators will handle. Experiments have shown that for maximum capacity the juice should

Plate No. 10.



INFLUENCE OF THE HEIGHT OF SYRUP ON THE HEAT TRANSMISSION COEFFICIENT.



be carried at such a height that when boiling the top tubes will be just covered. The gauge glass on the juice-chamber shows only the static head due to the weight of the juice; it does not show how high the juice inside is boiling, since the steam bubbles raise it up. If the juice ceased boiling and the bubbles subsided, the level inside would correspond approximately with the level in the gauge glass.

Viscosity of the Juice.—A sugar has more viscosity than water; it will not flow or move about as rapidly. The viscosity increases as the juice becomes more concentrated and as it becomes colder. The rapidity with which heat is transmitted depends to a large extent on the viscosity of the juice, since a viscous juice moves about more slowly, comes less in contact with the heated surfaces and steam bubbles have more difficulty in getting through the viscous juice and away from the tubes. In a set of evaporators the juice becomes thicker as it passes from one body to another, and at the same time colder, dropping from 110° C. in the first body to 60° C. in the last body. As both of these factors influence its viscosity, the juice in each successive body becomes more and more viscous. Plate No. 11 shows the influence of brix and viscosity on heat transference. The effect that this has on the heat transmission is seen from a series of tests made at Brush in 1909, where the coefficient of transmission of heat from the different bodies was as follows:

First body	39.0
Second body	37.2
Third body	33.1
Fourth body	25.2
Fifth body	15.4

This means that the heat transferred per square foot of heating surface for each degree difference in temperature between the steam or vapor in the tubes and the juice in the evaporator decreases in each successive body because of the increase in the viscosity of the juice. If we have a set of evaporators in which the area of the heating surface is the same for each body, and in which the same quantity of water must be evaporated, the temperature difference between the juice and the steam used for heating it will vary from one body to another, as can be seen in the following table showing some temperatures obtained from actual practice:

Body	Temperature of Steam or Vapor in Steam-Chest	Temperature of Juice	Difference
First	116° C.	111° C.	6° C.
Second	111° C.	103° C.	7° C.
Third	103° C.	94° C.	9° C.
Fourth	93° C.	80° C.	14° C.
Fifth	80° C.	60° C.	20° C.

Here it is seen that it requires 20° C. difference in temperature in the fifth body with its thick juice to transmit the same amount of heat that 6° C. difference will transmit in the first body where the juice is thin and less viscous.

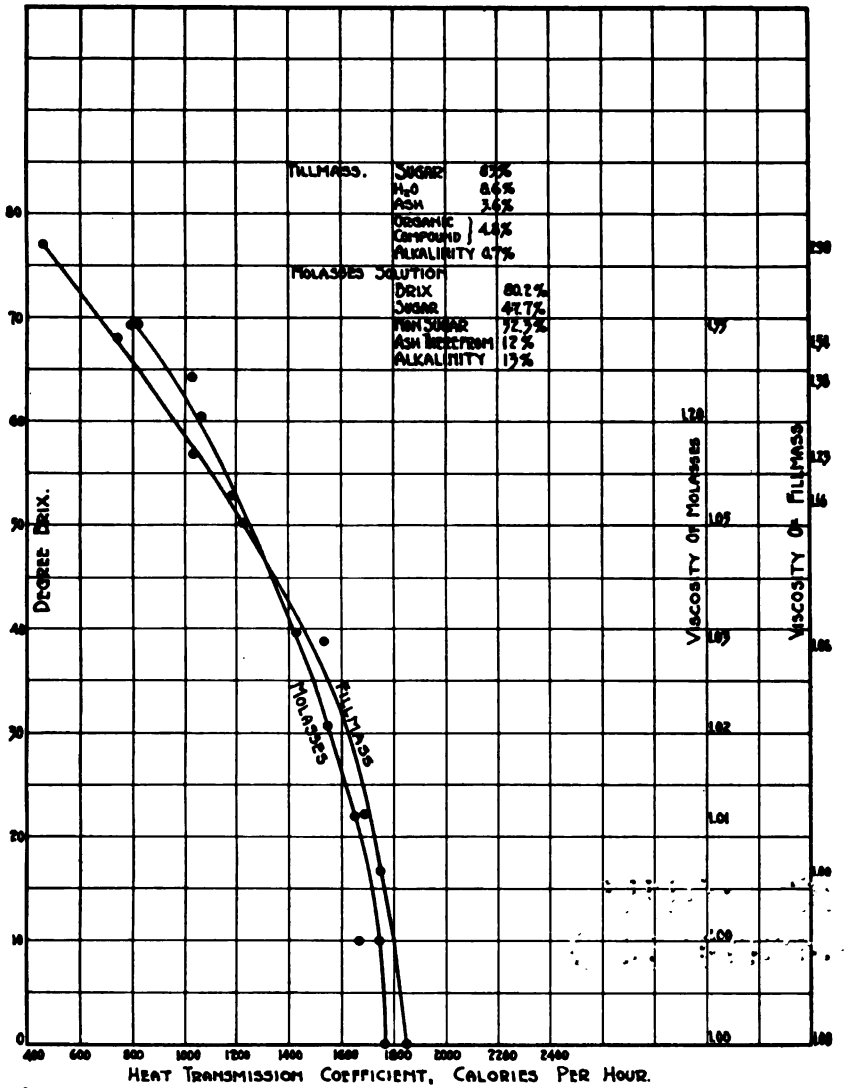
This range of temperature represents only one observation. Every set of evaporators takes its own range of temperature, depending on how much vapor heating is done, the respective areas of heating surface and other factors. If, however, the difference between the temperature of the steam and of the juice in any effect begins to increase, it is a sign that the tubes in that body are becoming dirty, for a dirty tube is a poor conductor, so the temperature difference must be increased to transmit the same amount of heat.

The use of more vapors from the first and second bodies increases the capacity of the evaporators. The explanation lies in the fact that in the first and second bodies the viscosity of the juice is low and more heat can be transmitted per degree temperature difference than in the last bodies. Now if vapors are taken away from the first bodies, they must do more work, their temperature differences will become a little greater (1° C. or 2° C.) and the temperature drop in the last bodies will be reduced the same amount; less water will be evaporated per square foot of heating surface in the last bodies since the temperature difference has been reduced; more water will be evaporated in the first bodies because the temperature difference will evaporate more water in the first bodies than in the last, and the capacity of the evaporators as a whole will be increased.

The addition of the melted sugar at second carbonation instead of at the blow-ups, although sometimes advisable for other reasons, raises the density of the juice entering the evaporators, increases its viscosity and decreases the capacity of the evaporators.

Temperature Difference.—The quantity of heat that a given heating surface will transmit depends upon the difference in temperature of the steam or vapor and the juice being heated, and the

Plate No. 11.



INFLUENCE OF DRIX AND VISCOSITY ON HEAT TRANSMISSION COEFFICIENT.

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greater this difference the greater will be the quantity of heat transmitted.

Now in a set of evaporators in a sugar factory, steam enters the first effect at about 116° C. and the thick juice leaves the last effect at a temperature of 58° C., a total difference in temperature of 58° C. This drop in temperature must be divided between the five different bodies. As stated above, the change in viscosity in the different bodies does not allow it to be devided equally; the last bodies must have a greater temperature drop than the first ones.

Increasing the temperature difference will increase the capacity of the evaporators. This increase can be attained in two ways, either by increasing the pressure of the entering steam and consequently its temperature, or by reducing the temperature of the juice in the last body. The pressure of the entering steam cannot be raised too high or the back pressure on the engines will become too great for their economical operation, and the pressure of the vapor in the first body may become so high as to be dangerous. The temperature of the juice in the last body is governed by the vacuum furnished by the condenser and vacuum pumps; therefore, this vacuum should be as high as possible. In the Colorado factories, if the vacuum falls below 22 inches of mercury, the system should be thoroughly investigated for air leakes.

If a set of quadruple evaporators of definite heating surface per body is already installed, the addition of a fifth body of the same heating surface does not increase the capacity of the evaporators, because the total drop in temperature which determines the capacity of the evaporators remains the same as before and the only difference is that the temperature drop is divided into five parts instead of four parts. The addition of the extra body does, however, increase the economy, because five pounds of water are evaporated by each pound of steam in a quintuple evaporator, instead of four pounds in a quadruple.

There is a small sugar loss in the evaporators due to two causes, namely, decomposition and entrainment. The decomposition loss is generally small and increases with the temperature and the length of time that the juice is boiled. In our factories the temperature of the boiling is pretty well established, but the time that the juice is subjected to the heat can be reduced by keeping the level of the juice in the evaporators low.

The entrainment loss is caused by the juice being carried over mechanically with the vapors and the danger is greatest in the last

body because of the great velocity of the vapors and the high concentration of the sugar there. To prevent this loss a series of De Cluy baffles are placed in the vapor part of the last body and catchalls are provided in the line leading to the condensers. The entrainment of juice from the first bodies can usually be prevented if the levels are not too high; cottonseed oil is used if the juice is foaming badly.

CAPACITY OF EVAPORATORS

It is now possible to make up a summary of the factors which affect the capacity of evaporators.

(1) The tubes of the evaporator should be kept clean in order that a maximum quantity of heat may be transmitted.

(2) The condensed water must be removed as rapidly as formed.

(3) The air and ammonia must be removed from the steam-chests by the proper manipulation of the valves on the ammonia lines in such a way that no air or gas is allowed to collect in the steam-chests and at the same time a minimum quantity of vapor or steam goes out with the ammonia.

(4) The juice in the bodies should be carried at the proper level so that when boiling the top tubes will be just covered.

(5) The greater the viscosity of the juice the less will be the capacity of the evaporators and for this reason melted sugar should be added at the blow-ups instead of to second carbonation. (This statement is from the standpoint of the evaporators only; it may, for other reasons, sometimes be advisable to add the melted sugar at second carbonation instead of to the blow-ups.)

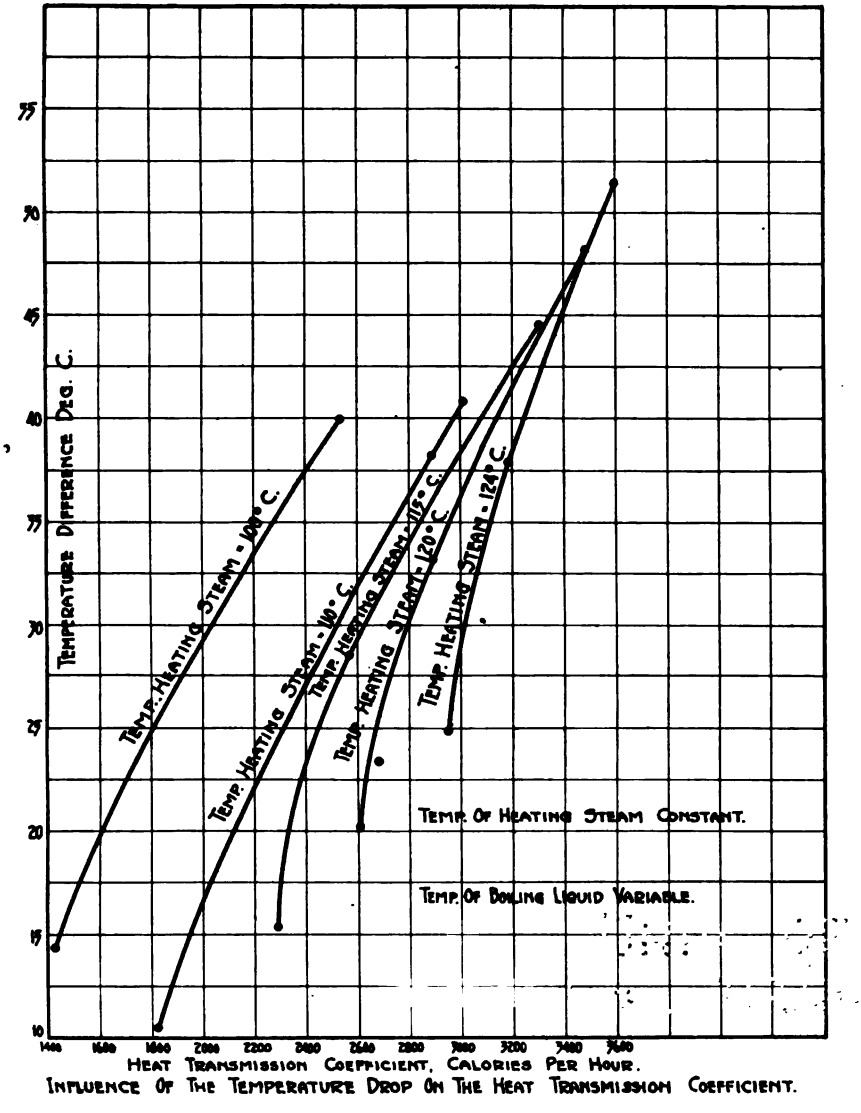
(6) The greater the difference between the steam entering the first body and the juice leaving the last body, the greater the capacity of the evaporators. For this reason the vacuum in the last body should be as high as possible and all air leaks should be avoided.

(7) The use of a maximum of vapor for heating increases the capacity of the evaporators.

STEAM ECONOMY

Steam economy in a sugar factory depends upon a great many factors such as (1) the efficiency of the boiler house; (2) the proper balance of steam-consuming engines and pumps; (3) the quantity of juice drawn on the battery and the amount of water used on

Plate No. 12.


TEMPERATURE DIFFERENCE DEG. C.
TEMP. HEATING STEAM - 100° C.
TEMP. HEATING STEAM - 110° C.
TEMP. HEATING STEAM - 115° C.
TEMP. HEATING STEAM - 120° C.
TEMP. HEATING STEAM - 124° C.
TEMP. OF HEATING STEAM CONSTANT.
TEMP. OF BOILING LIQUID VARIABLE.
HEAT TRANSMISSION COEFFICIENT, CALORIES PER HOUR.

INFLUENCE OF THE TEMPERATURE DROP ON THE HEAT TRANSMISSION COEFFICIENT.

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the filter presses; (4) the dilution of sugar and syrups and the amount of reboiling done on the sugar end; and (5) the use of vapors from the evaporators for heating the juices instead of live or exhaust steam.

The efficiency of the boiler house will be treated in a subsequent chapter. The effect of the draft on the battery and the amount of wash water used on the filter presses has been discussed in the chapters on those subjects, while the proper handling of sugar end products will be taken up in the sugar end chapter. Therefore, we shall confine this discussion to the use of vapors from the evaporators for heating juices and the effect which this practice has on the steam economy of a sugar factory.

Heating With Vapors.—In the preceding parts of this chapter we have studied the operation of quintuple evaporators from the standpoint of evaporation only. We saw that the use of part of the first vapors for heating increases the capacity of the evaporators; now we shall see what else can be done by using these and other vapors for heating. In actual practice, most of the heating of the juice is done with vapors instead of live or exhaust steam. Vapors heat the juice in the battery, before and after carbonation and filtration, before entering the evaporators and at other stations. The quantity of steam thus saved can be calculated by the formula:

$$\text{Saving} = \frac{\text{Kind of vapor used.}}{\text{Number of bodies in evaporator.}}$$

Details of such calculations are shown in plates Nos. 13 and 14. For example, let us assume that the raw juice can be heated by live or exhaust steam or by first vapor or second vapor; what, then, will the saving be if first or second vapor is used instead of live or exhaust steam?

FIRST VAPOR: $\text{Saving} = \frac{\text{Kind of Vapor Used}}{\text{No. of Bodies in Evaporator}} = 1/5 =$ 1/5 of the total steam needed for heating the raw juice can be saved by using first vapor instead of live or exhaust steam.

SECOND VAPOR: $\text{Saving} = \frac{\text{Kind of Vapor used}}{\text{No. of Bodies in Evaporator}} = 2/5 =$ 2/5 of the total steam needed can be saved by using second vapor instead of live or exhaust steam.

In a factory cutting 100,000 tons of beets during the campaign, there would be about 130,000 tons of raw juice, to be heated from,

say, 45° C. to 85° C. This would require 9,656 tons of exhaust steam, which is equivalent to 1,608 tons of coal. If first vapor were used, 1/5 of the coal would be saved; that is, 1,608 × 1/5 = 322 tons; if second vapor were used 1,608 × 2/5 or 643 tons of coal would be saved.

In our new factories provision has been made to use first, second, third and fourth vapor for the various heating devices.

Fourth vapor is used for the first heating of the raw juice and from this source about 60% of the total heat needed for this service is obtained.

Third vapor heats the raw juice after it leaves the fourth vapor heaters and about 23% of the total heat needed is derived from this source.

Second vapor heats the battery (third or fourth vapor is too low in temperature) and finishes heating the raw juice after it leaves the third vapor heaters.

First vapor is used for heating the first carbonation juice on the way to the presses, the second and third juice before it enters the presses, the thick juice after leaving the evaporator, and also furnishes the heat for boiling the calandria or raw pans.

In a factory cutting 100,000 tons of beets per campaign this vapor heating compared with the old way of heating with live or exhaust steam saves:

By fourth vapor heating.....	852	Tons of Coal
By third vapor heating.....	208	Tons of Coal
By second vapor heating.....	500	Tons of Coal
By first vapor heating.....	520	Tons of Coal
Total	2,080	Tons of Coal

It is therefore readily apparent that vapor heating plays a very important part in the steam economy of a sugar house and at every factory the vapor heating equipment provided should be used to the very greatest extent possible. At one or two factories instances have been known in the past where exhaust steam has been turned into the second vapor with the idea that it helped in the heating of the battery. This practice not only causes a loss of coal due to the use of a portion of exhaust steam instead of vapor for this work, but it also disarranges the pressure balance of the evaporators and actually decreases their capacity.

Plate No. 13.

Approximate General Savings Due To Vapor Heating.

	From Quintuple Evap.			From Quadruple Evap.			From Triple Evap.		
Kind of Steam or Vapor Used.	Coal Used	Coal Saved	Fra ctn.	Coal Used	Coal Saved	Fra ctn.	Coal Used	Coal Saved	Fra ctn.
Exhaust or Live	100	0	0	100	0	0	100	0	0
First Vapor	80	20	$\frac{1}{5}$	75	25	$\frac{1}{4}$	$66\frac{2}{3}$	$33\frac{1}{3}$	$\frac{1}{3}$
Second "	60	40	$\frac{2}{5}$	50	50	$\frac{2}{4}$	$33\frac{1}{3}$	$66\frac{2}{3}$	$\frac{2}{3}$
Third "	40	60	$\frac{3}{5}$	25	75	$\frac{3}{4}$	0	100	$\frac{3}{3}$
Fourth "	20	80	$\frac{4}{5}$	0	100	$\frac{4}{4}$	-	-	-
Fifth "	0	100	$\frac{5}{5}$	-	-	-	-	-	-

Example :- If 100 Tons of coal are required to do a certain amount of heating, using live or exhaust steam if the same heating can be done with 1st Vapor it will require 80-75-$66\frac{2}{3}$ tons of coal, if 1st Vapor is taken from Quintuple, Quadruple or Triple Evap.

Formula:- Saving = $\frac{\text{Kind of Vap. Used}}{\text{No. Bodies in Evap.}}$ = $\frac{1}{5}$ - $\frac{1}{4}$ - $\frac{1}{3}$ for above.

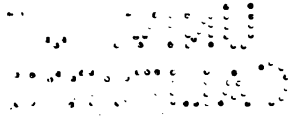
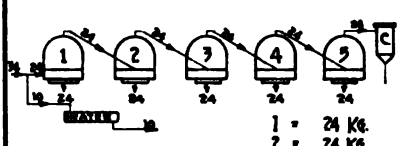


Plate No. 14.

CALCULATION SHOWING THE VALUE OF VAPOR HEATING.

ASSUMPTION– 150 Kg. OF THIN JUICE. ✓
30 Kg. OF THICK JUICE. ✓
120 Kg. OF WATER TO BE EVAPORATED IN QUINTUPLE EFFECT EVAPORATORS. ✓
100 Kg. OF THIN JUICE TO BE HEATED 54°C. IN HEATERS, OR $\frac{54 \times 100}{340}$ = 16 Kg. STEAM REQ.

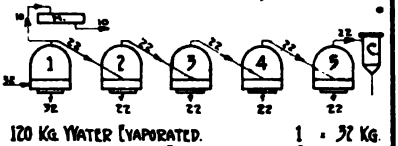
1- ALL HEATING DONE BY EXHAUST STEAM.



EVAPS. $\frac{120}{5}$ = 24 Kg.
HEATERS 10 = 10 Kg.
TOTAL 34 Kg. STEAM.

1 = 24 Kg.
2 = 24 Kg.
3 = 24 Kg.
4 = 24 Kg.
5 = 24 Kg.
TOTAL = 120 Kg.

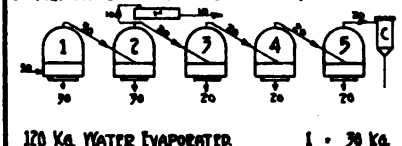
2.- HEATING DONE BY EXHAUST & 1ST VAPOR.



120 Kg. WATER EVAPORATED.
10 Kg. WATER, SINGLE EFFECT.
110 Kg. WATER, QUINTUPLE EFFECT.
$\frac{110}{5}$ = 22 Kg.
10 Kg.
32 Kg. TOTAL STEAM.

1 = 32 Kg.
2 = 22 Kg.
3 = 22 Kg.
4 = 22 Kg.
5 = 22 Kg.
TOTAL = 120 Kg.

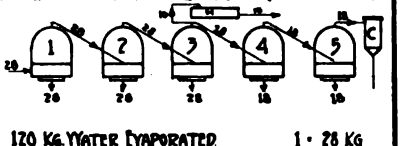
3. HEATING DONE BY EXHAUST & 2ND VAPOR.



120 Kg. WATER EVAPORATED.
20 Kg. WATER, DOUBLE EFFECT.
100 Kg. WATER, QUINTUPLE EFFECT.
$\frac{100}{5}$ = 20 Kg.
$\frac{20}{2}$ = 10 Kg.
30 KG. TOTAL STEAM.

1 = 30 Kg.
2 = 30 Kg.
3 = 20 Kg.
4 = 20 Kg.
5 = 20 Kg.
TOTAL = 120 Kg.

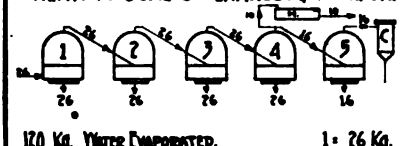
4–HEATING DONE BY EXHAUST & 3RD VAPOR.



120 Kg. WATER EVAPORATED.
90 Kg. WATER, TRIPPLE EFFECT.
90 Kg. WATER QUINTUPLE EFFECT.
$\frac{90}{5}$ = 18 Kg.
$\frac{10}{2}$ = 10 Kg.
28 KG. TOTAL STEAM.

1 = 28 Kg
2 = 28 Kg
3 = 28 KG.
4 = 18 KG.
5 = 18 Kg.
TOTAL = 120 Kg.

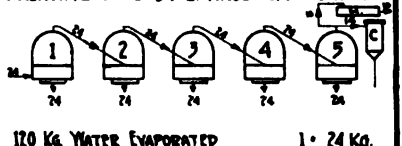
5–HEATING DONE BY EXHAUST & 4TH VAPOR.



120 Kg. WATER EVAPORATED.
40 Kg. WATER, QUADRUPLE EFFECT.
80 Kg. WATER, QUINTUPLE EFFECT.
$\frac{80}{5}$ = 16 Kg
$\frac{40}{4}$ = 10 Kg.
76 Kg. TOTAL STEAM.

1 = 26 Kg.
2 = 26 Kg.
3 = 26 Kg
4 = 26 Kg.
5 = 16 Kg.
TOTAL = 120 Kg.

6–HEATING DONE BY EXHAUST & 5TH VAPOR.



120 Kg. WATER EVAPORATED
70 Kg. WATER, QUINTUPLE EFFECT
70 Kg. WATER, QUINTUPLE EFFECT.
$\frac{70}{5}$ = 14 Kg.
$\frac{10}{1}$ = 10 Kg.
24 Kg TOTAL STEAM.

1 = 24 Kg.
2 = 24 Kg.
3 = 24 Kg.
4 = 24 Kg.
5 = 24 Kg.
TOTAL = 120 Kg.

SAVING BY USE OF 5TH VAPOR FOR HEATERS.

HEATING MEDIUM.	TOTAL Kg. STEAM	MIN. STEAM FOR EVAP.	Kg. SAVING.
ALL EXHAUST STEAM.	34	24	10 – 10 = 0
EXHAUST & 1ST VAPOR.	32	24	10 – 8 = 2
EXHAUST & 2ND VAPOR.	30	24	10 – 6 = 4
EXHAUST & 3RD VAPOR.	28	24	10 – 4 = 6
EXHAUST & 4TH VAPOR.	26	24	10 – 2 = 8
EXHAUST & 5TH VAPOR.	24	24	10 – 0 = 10

NOTE– 5TH VAPOR CAN NOT ALWAYS BE USED, AS IT IS NECESSARY TO HEAT THE JUICE FROM 80°C. TO 95°C. THE TEMPERATURE OF THE 5TH VAPOR IS FROM 95°C. TO 62°C.

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The use of vapors for heating changes the operation of the evaporators as compared with their operation when only evaporation is considered. More steam must be introduced into the first bodies, more water is evaporated from them and consequently less water is evaporated in the latter bodies. Plate No. 15 shows a diagrammatic sketch of two sets of evaporators; in both cases 120 pounds of water are evaporated from the juice, but in the first case no vapor is used for heating, while in the second case a certain amount of vapor heating is practiced. In the first set of evaporators, 24 pounds of steam is fed to the first body of the evaporator and 24 pounds of water is evaporated in each body, making a total of 120 pounds in the five bodies; and 40 pounds of steam is used for heating purposes, which makes a total of 64 pounds of steam needed for both evaporating and heating.

In the second set of evaporators, 52 pounds of steam is fed to the first body and 52 pounds of water is evaporated from the juice in this body. Of this 52 pounds of first vapor, 20 pounds is used for heating and 32 pounds pass to the steam-chest of the second body, where it evaporates 32 pounds of water from the juice. The 32 pounds of second vapor passing from the second body divides into two parts; 20 pounds goes off for heating and 12 pounds goes to the steam chamber of the third body. In this example no heating is done with the third or fourth vapors and 12 pounds of water is evaporated in the third, fourth and fifth bodies.

Summing up we see that the evaporation in the second set of evaporators was divided as follows:

First body	52 pounds
Second body	32 pounds
Third body	12 pounds
Fourth body	12 pounds
Fifth body	12 pounds
Total	120 pounds

At the same time 40 pounds of vapor was furnished for heating purposes. The same quantity of work was done by the second set of evaporators as by the first set and with the use of only 52 pounds of steam instead of 64 pounds.

To provide for the greater amount of evaporation that must be accomplished in the first bodies, the areas of their heating sur-

faces are made larger. In the new houses the total area of heating surface is apportioned as follows:

First body	5,507 Sq. Ft.
Second body	5,507 Sq. Ft.
Third body	3,612 Sq. Ft.
Fourth body	3,612 Sq. Ft.
Fifth body	3,612 Sq. Ft.
Total	25,420 Sq. Ft.

The use of a large amount of vapor for heating increases the capacity of the evaporators as a whole, as was shown in the discussion of evaporator capacity.

The factors which increase the steam economy in a sugar factory may be summed up as follows:

(1) A low draft on the battery and a minimum use of water on the first and second presses, so that a minimum of water must be evaporated.

(2) The use of vapors for heating purposes instead of live or exhaust steam.

(3) Concentration of the juice to a high density (68° to 70° Brix) in the evaporators, where one pound of steam evaporates five pounds of water. The water left in the thick juice as it leaves the evaporators must be removed in the pans, where one pound of steam evaporates only one pound of water.

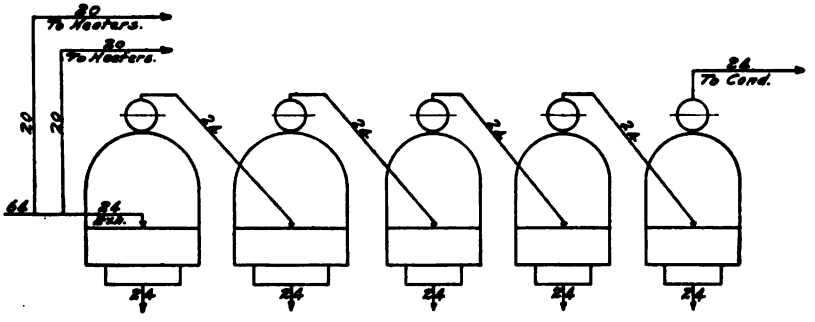
(4) The dilution of the sugar end syrups as little as possible.

(5) The proper lagging and insulation of all tanks and pipe lines to reduce radiation to a minimum.

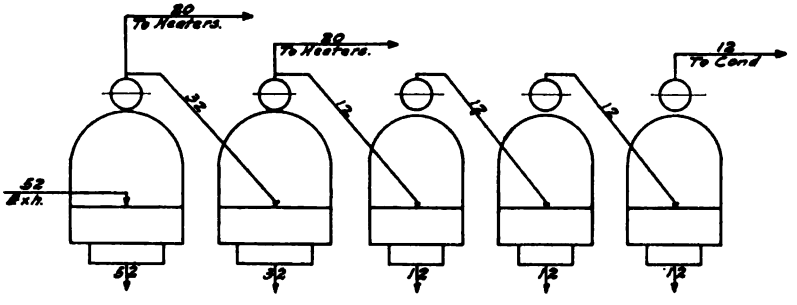
(6) An efficient boiler house. (This will be discussed in a subsequent lecture.)

The more serious students should study plates Nos. 16 and 17, which show in the form of a steam balance, a comparison of the steam and coal used per 100 kg. of beets in a non-Steffen house in 1907 as compared with that required in one of our new non-Steffen houses. These plates show that our progress in steam economy in the past twelve years has been great.

Plate No. 15.



160 Lbs. Thin Juice.
40 . Thick .
120 . Water Evap'd. Quint. Req. 24 Lbs. Steam.



160 Lbs. Thin Juice.
40 . Thick .
120 . Water Evaporated.
20 . . . Single Eff. Req. 20 Kg. Steam.
100 .
40 . . . Double . . 20 .
60 . Quintuple . . 12 .

CALCULATION SHOWING STEAM SAVING BY USING VAPOR FOR HEATING INSTEAD OF EXHAUST STEAM

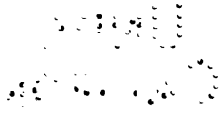


Plate No. 16

Steam Required Per 100 Kg. Beets.
Non-Steffens House - As Windsor in 1907.

Station		Live Exh	1st Vapor.
Battery.	Introduced - 100 Kg. Beets @ 0°C. " 230 " Water @ 0°C. Obtained - 130 Kg. of Raw J. @ 24°C = 3120 Cal. " 100 " " Pulp @ 17°C = 1700 " " 100 " " P.W.W. @ 17°C = 1700 " Total = 6520	12.1	
Raw J. Heaters.	130 Kg. R.J. - heated 44° - (24°-68°)		10.6
1st Carb. Coils.	140 Kg. Juice " 30° - (58°-88°)	7.7	
2nd Carb. Coils.	150 Kg. Juice " 13° - (80°-93°)	3.6	
3rd Sat. Coils.	150 Kg. Juice " 10° - (85°-95°)	2.7	
Evaporators.	150 Kg. Thin Juice heated 15° - (90°-105°) 35 Kg. Thick " 115 Kg. Water Evaporated. 10.6 Kg. " " Single Eff. Requires 104.4 Kg. " " Quad. " "	4.1 10.6 26.1	
Blow Up Coils.	42 Kg. Thk. J. & M.S. heated 55° to 95°	3.1	
White Pan.	30 Kg. Thk. J., M.S. & H.W. 25 Kg. Fillmass. 15 Kg. Water Evaporated - Requires	15.0	
Raw Pan.	17 Kg. Pan Liquor heated 45° C. 11 Kg. R. Fillmass. 6 Kg. Water Evaporated - Requires	6.0	
Granulator.		1.0	
Radiation.		15.0	
	Total Steam.	107.0	

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Plate No. 17.

Steam Required Per 100 Kg. Beets.
Non Steffens Equipped as our New Factories.

Station.		Live. Exh.	1st Vapor	2nd Vapor	3rd Vapor	4th Vapor
Battery.	Introduced 100 Kg. Beets @ 0° " 230 Kg. Water @ 50° Cal. 11500 Cal. Total = 11500 " Obtained 130 Kg. Raw J. @ 43°C = 5590 Cal. " 100 Kg. Pulp @ 46°C = 4600 " " 100 Kg. P.W.W. @ 46°C = 4600 " Total = 14790 " 11800 " 3290 "			6.0		
Raw J. Heaters.	130 Kg. heated 43° to 85°			2.3	1.9	5.8
1st Carb. Heater.	140 Kg. " 10°C (80° to 90°)		2.6			
2nd " "	145 Kg. " 10°C (85° to 95°)		2.7			
3rd Sat. "	145 Kg. " 8°C (87° to 95°)		2.2			
Thin J. Heaters.	145 Kg. " 15°C (90° to 105°)		4.0			
Thick J. Heaters.	30 Kg. " 25°C (60° to 85°)		1.4			
Raw Pan Calandria.	14.0 Kg. Pan Liquor 11.0 Kg. Raw Fillmass 3.0 Kg. Water Evaporated		3.0			
Evaporator.	145 Kg. Thin Juice. 30 " Thick " 115 " Water Evaporated 15.9 " " " Single Eff. Rep. 15.9 99.1 " 16.6 " " " Double " " 8.3 82.5 " 5.7 " " " Triple " " 1.9 76.8 " 23.2 " " " Quad. " " 5.8 53.6 " " " Quin. " " 10.7					
Blow Ups.	37 Kg. heated 20°C.	1.3				
White Pan.	45 Kg. Pan Liquor. 35 " Fillmass 10 " Water Evaporated	10.0				
Granulator.		1.0				
Radiation.		10.0				
	Total Steam	64.9				

PROBLEMS

Formula for Evaporation of Water

Let A = Tons Beets Cut
M = % Sugar in Beets
C = % Sugar in Pulp
D = % Sugar in Pulp Water
E = Sugar in Lime Cake % on Beets
B = Brix of Thin Juice
G = Purity of Thin Juice
F = Brix of Thick Juice
Q = Tons Sugar in Thin Juice
P = Tons Thin Juice
R = Tons Thick Juice
S = Tons Water Evaporated

$$Q = A\ (M - C - D - E)$$

$$P = \frac{Q}{G} \times \frac{100}{B}$$

$$R = \frac{Q}{G} \times \frac{100}{F}$$

$$S = P - R$$

(1) A factory cuts 1,200 tons of beets per day and the beets contain 16.0% sugar; the losses are .20% in pulp, .09% in pulp water and .09% sugar in lime cake, all expressed as % on beets; the brix of the thin juice is 12.2 and its purity 89.3; and the brix of the thick juice is 66.2. How much water must be evaporated by the evaporators each day?

(2) A factory slices 1,225 tons of beets per day uses a draft of 130, and heats the raw juice from 45° C. to 85° C. How many tons of coal will be saved per day if first vapor is used for this heating instead of live steam? How much coal per day will be saved if second vapor is used instead of live steam? How much per day does second vapor heating save compared with first vapor heating?

(3) Assume that a sugar factory slices 210,000 tons of beets per campaign containing 16.21% sugar, the pulp contains .18%

sugar, the pulp water .09%, and the sugar loss on lime cake is .06% on beets. How much water must be removed in the evaporators if the purity of the thin juice is 90.0, its Brix 12.0° and the Brix of the thick juice 65.0°? How much water must be removed in the evaporators if the purity of the thin juice is 90.0, its Brix 13.0° and the Brix of the thick juice at 65.0°? How many tons of coal will be saved in the second case over and above that needed in the first? What is the value of this coal at $3.00 per ton?

CHAPTER NO. VII

CRYSTALLIZATION

SECTION A

The thick juice from the evaporators is pumped through a set of heaters to the blow-ups, where remelt sugar is added to it and the mixture is treated with sulphur dioxide gas. The evaporation of the juice brings about an increase in alkalinity and color, and it is the purpose of the blow-up station to reduce the alkalinity of the juice and bleach it by treatment with sulphur dioxide gas. After treatment in the blow-ups the juice is heated to about 95° C. and sent through the thick juice filters, where the sediment is filtered out, and the thick juice, now called "blow-up thick juice" or "thick juice and melted sugar", is pumped to the pan floor tanks.

The thick liquor sent to the pan floor contains sugar and non-sugars in solution, and to obtain the sugar in a marketable form, it is necessary to separate the sugar from the non-sugars. This separation is made by taking advantage of the natural property of sugar to separate as crystals from its "supersaturated" solutions. This process is called crystallization.

In a discussion of crystallization certain technical terms such as "saturation", "supersaturation", "mother liquor", etc., are used very extensively, and before proceeding further an explanation of these terms will be given.

If pure sugar is added to pure water, the water will dissolve a definite amount of sugar, depending on the temperature; and the higher the temperature, the greater the amount of sugar which may be dissolved. At a given temperature a unit of water will dissolve a constant quantity of sugar, and the following table shows the quantity that one part of water will dissolve at different temperatures. The complete table, known as the Herzfeld Solubility Table, is given in Section B of this chapter.

Temperature Degrees Centigrade	Parts of Sugar Dissolved by One Part of Water
0°	1.79
10°	1.90
20°	2.04
30°	2.19
40°	2.38
50°	2.60
60°	2.87
70°	3.20
80°	3.62
90°	4.15
100°	4.87

When a sugar solution contains all the sugar that can be dissolved at a certain temperature, it is said to be saturated at that temperature.

A saturated sugar solution at 70° C. will contain 3.20 parts of sugar per one part of water, while a saturated sugar solution at 80° C. will contain 3.62 parts of sugar to one part of water. However, a sugar solution which is saturated at 80° C. may, by careful manipulation and the avoidance of agitation, be cooled down to 70° C. without any of the sugar separating out as crystals. Under this condition the solution at 70° C. contains more sugar than enough to saturate it and is said to be "supersaturated". Any jarring or agitation of a supersaturated pure sugar solution will cause a separation of sugar crystals.

Thus far the consideration of the subject of saturation and supersaturation has been limited to pure sugar solutions, while in ordinary factory practice the beet juices with which we work contain not only sugar but also non-sugars. These impure juices act differently than pure sugar solutions in that more sugar is dissolved per part of water at any given temperature than would be dissolved if no non-sugars were present, and, as the concentration of non-sugars increases, the amount of sugar that each part of water will hold in solution is increased until a point is reached where no more sugar will crystallize out regardless of the concentration or supersaturation of the solution. This condition is reached with beet molasses, for at this point (the molasses stage) 1.5 parts of sugar are in solution associated with 1.0 part of non-sugar, and further crystallization is impossible.

The fact that non-sugars retard the crystallization of sugar makes it necessary in practical factory operation to bring the

syrups to a supersaturated condition before crystallization will take place. Also, a greater supersaturation is needed to cause the formation of crystals than is required for the growth of the crystals after they have been started, and for this reason the sugar boiler keeps the syrup at a higher concentration during the graining period than he does during the growing or boiling period.

"Mother Liquor" may be defined as the liquid in which the crystals are forming or have formed, and the term "massecuite" is applied to the mixture of crystals and mother liquor. In the case of sugar factory massecuites the mother liquor contains the non-sugars originally present in the juice. Thus in a practical way it may be seen that the high green represents the mother liquor of white massecuite, and low green represents the mother liquor of remelt massecuite, after the complete crystallization has taken place.

Crystallization in a beet sugar factory is performed in an apparatus known as a vacuum pan, and the process is divided into white sugar crystallization and remelt sugar crystallization.

The usual vacuum pan consists of a cast iron cylinder from 10 to 14 feet in diameter, with a capacity of from 1,000 to 2,000 cubic feet, closed on the bottom with a conical section fitted with a large outlet line and valve, and closed on top with a dome shaped section connected by vapor pipes to the juice catch-all and condenser. The lower part of the inside of the pan is equipped with either steam coils or a calandria, which furnishes the necessary heating surface for the evaporation of the water. Plate No. 18 shows the cross-section of a coil pan, Plate No. 19 shows the cross-section of a calandria pan, and Plate No. 20 shows an assembled pan ready for operation. In a coil pan the steam is inside the coils and the juice to be evaporated is on the outside, while in a calandria pan the steam is on the outside and the juice circulates inside the vertical tubes.

So far the exact manipulation of the vacuum pan has never been standardized, but the fundamental plan of operation is the same in all cases, and the following may be considered by the new student as a more or less representative method of procedure.

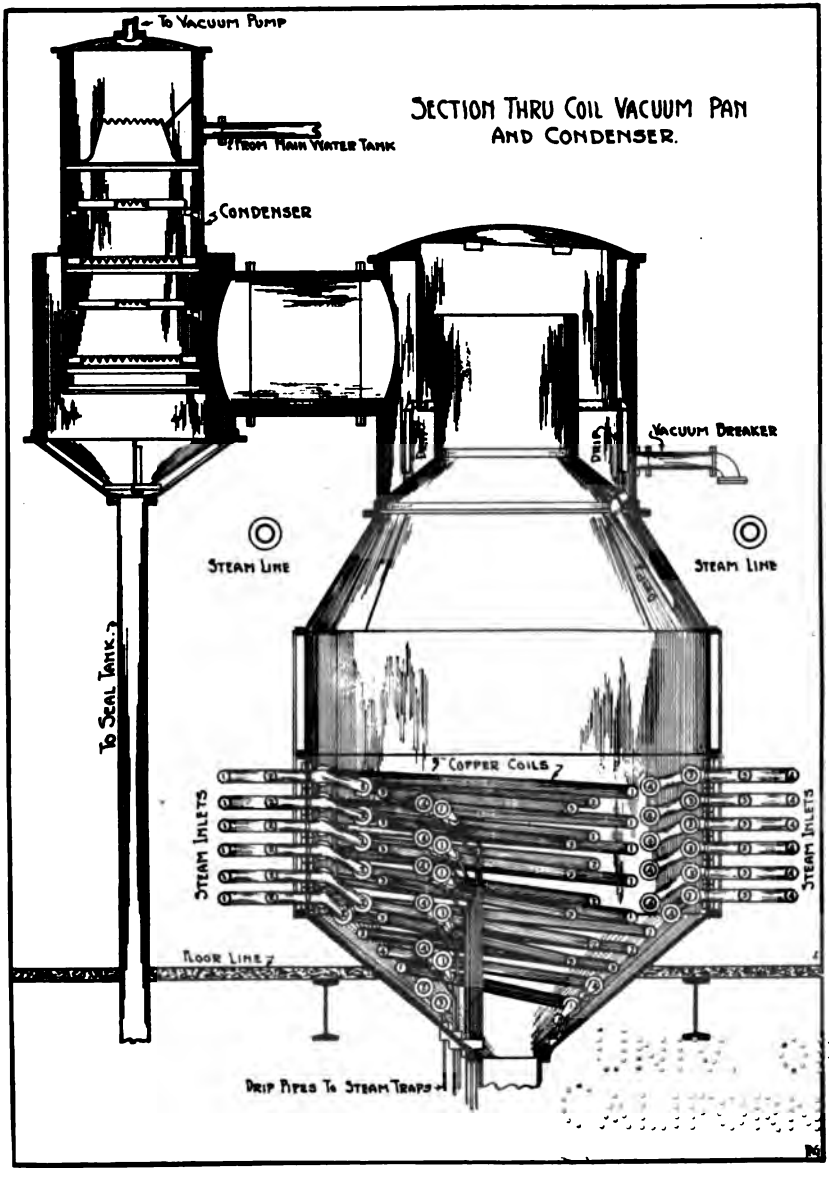
The pan is closed up, all air valves, water valves, etc., are closed tightly, a small amount of water is turned on the condenser, and the vacuum pump is started. This creates a vacuum within the pan, and when the vacuum is equivalent to 10 or 11 inches of mercury, the charging valve is opened and the pan is filled about one-third full of thick liquor in the case of white pans, or of high

green in the case of remelt pans. The first juice drawn into the pan is called the "charge" and is rapidly evaporated at a temperature of from 70° C. to 80° C. until the sugar begins to crystallize out, or, in ordinary sugar factory terms, until "grain" comes in. The sugar boiler, at this point, takes frequent samples of the boiling mass and examines them on his test glass. The formation of grain is allowed to continue until, in the judgment of the sugar boiler, enough crystals are present to give, at the end of the boiling, the desired quantity of proper sized crystals. When this point is reached, the supersaturation of the mass is reduced by the introduction of more syrup and by raising the temperature to such a point that no new crystals will be formed. From this time on the sugar boiler endeavors, by the more or less continuous addition of new syrup and the continuous evaporation of the water from this syrup, so to maintain the density or supersaturation of the crystallizing mass that no further formation of crystals will take place, and yet those crystals already formed will continue to grow by taking up the sugar from the solution until, by the time the pan is finished, they will be of the proper size.

During the last few years some of the factories are obtaining the grain in the vacuum pans by what is known as "seeding". By this method the charge is evaporated until the crystals are just ready to form, at which time about one quart of sugar dust (finer than 90 mesh) is introduced into the pan through the proof stick connection. The addition of this sugar dust seems to act as a shock to the mass and causes the almost immediate formation of grain. The advantages claimed for the seeding method of graining are that the length of time needed to grain the pan is reduced, and, since the grain is all formed at once, the growing time of all crystals is the same and a more even sized product results.

The manipulation of the vacuum pan is the same whether white or remelt massecuite is being boiled, but, owing to the fact that the remelt massecuite is of a lower purity than the white massecuite, the time needed for the crystallization is longer, and the extent to which the crystallization can be carried is more limited. It requires only about 3 hours to boil a white pan and from 45 to 50 per cent crystallization is obtained, while with remelt massecuite only 35 to 40 per cent crystallization is usually obtained, and the total time required for crystallization is from 48 to 72 hours. The remelt crystallization can be obtained either by boiling in vacuum pans for 48 to 72 hours or by boiling from 9 to 12 hours in the vacuum pan and then transferring to crystallizers, where the

Plate No. 18.


To Vacuum Pump
From Main Water Tank
Condenser
Section Thru Coil Vacuum Pan
And Condenser.
Vacuum Breaker
Drip
Steam Line
Steam Line
To Seal Tank.
3" Copper Coils
Steam Inlets
Steam Inlets
Floor Line
Drip Pipes To Steam Traps

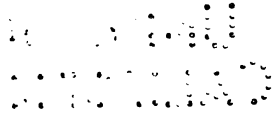
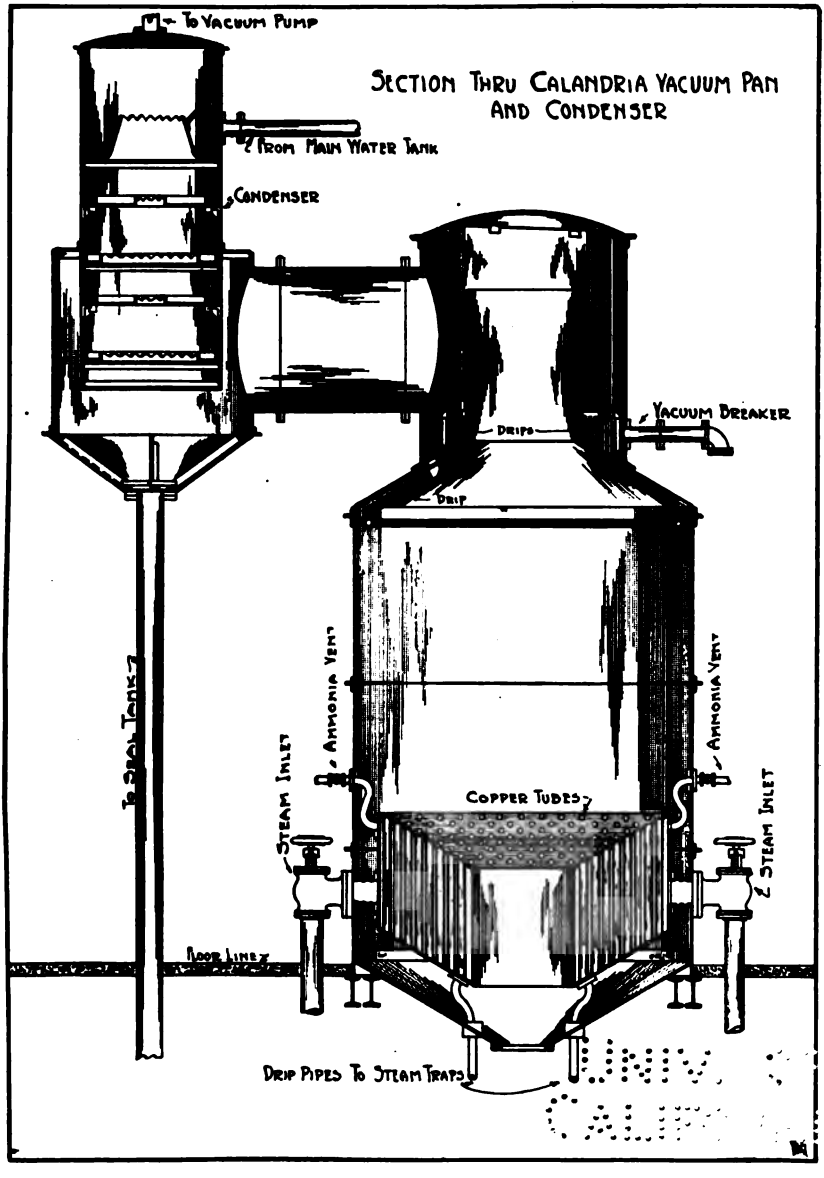


Plate No. 19.


To Vacuum Pump
Section Thru Calandria Vacuum Pan
And Condenser
From Main Water Tank
Condenser
Vacuum Breaker
Drips
Drip
To Seal Tank
Ammonia Vent
Ammonia Vent
Steam Inlet
Steam Inlet
Copper Tubes
Floor Line
Drip Pipes To Steam Traps

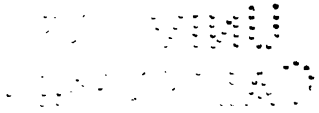
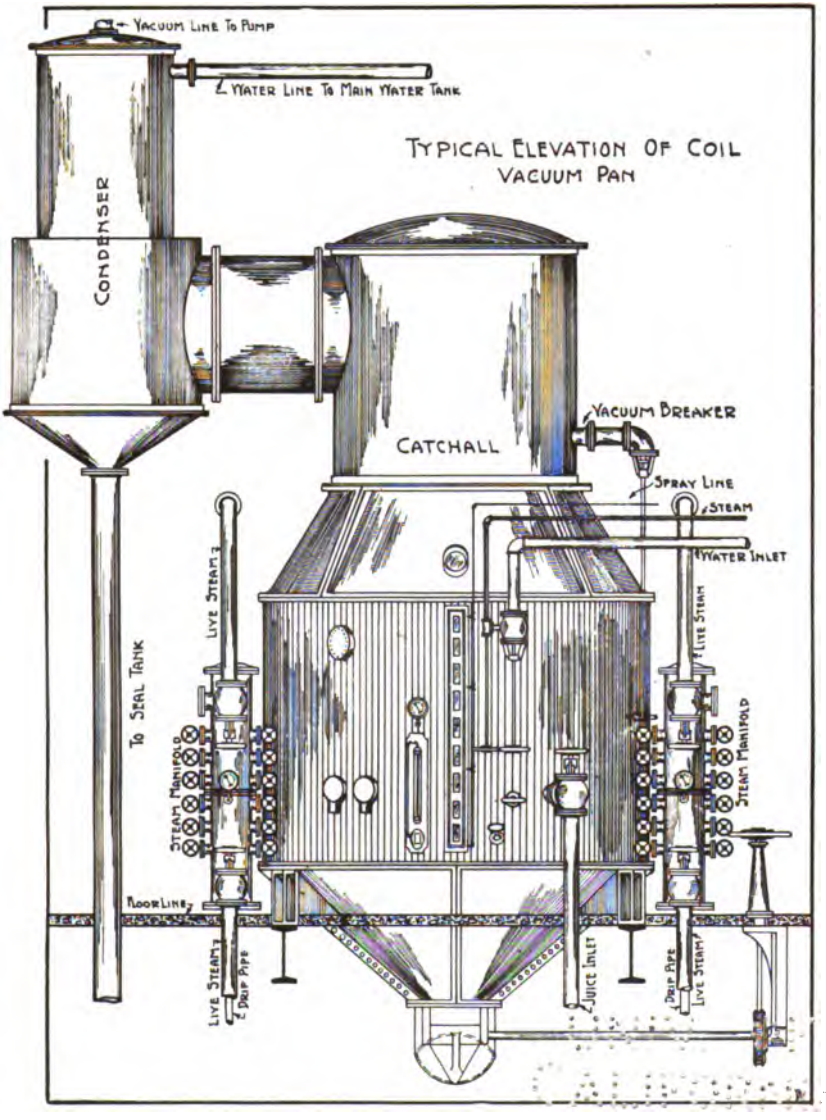
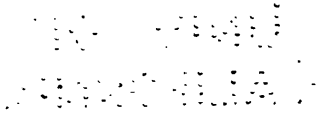


Plate No. 20.


VACUUM LINE TO PUMP
WATER LINE TO MAIN WATER TANK
TYPICAL ELEVATION OF COIL VACUUM PAN
CONDENSER
CATCHALL
VACUUM BREAKER
SPRAY LINE
STEAM
WATER INLET
LIVE STEAM
TO SEAL TANK
STEAM MANIFOLD
FLOOR LINE
DRIP PIPE
JUICE INLET



massecuite can be gradually cooled and the crystallization completed. A few factories perform this work in Grosse pans, but in the majority of factories crystallizers are provided and the proper operation of these crystallizers becomes an important part of the crystallization process.

The practical management of the crystallizing process in a beet sugar factory involves the proper handling of the various syrups and second products, and a discussion of crystallization would be incomplete without an outline of the methods used in handling these syrups.

The thick liquor, after leaving the presses, is pumped to the pan floor, drawn into the white pan, grained and boiled as explained above. Only 45 to 50 per cent of sugar on the dry substance of the massecuite will crystallize out, and there remains, after boiling, a mass consisting of sugar crystals suspended in the mother liquor. This mass is called "White Massecuite", and is sent to the centrifugals, where the sugar crystals are removed by centrifugal force from the mother liquor containing the impurities. The last traces of the mother liquor are removed from the sugar crystals by spraying with pure warm water, after which the sugar is discharged, dried and sacked. The mother liquor thrown off from the centrifugals is known as "High Green", while the syrup thrown off during the washing is called "High Wash". The high wash is taken back into the following white pan, but the high green syrup, which is still probably of from 75.0 to 78.0 purity, must be boiled again to secure a final molasses of 60.0 purity. To accomplish this, the high green is drawn into the remelt pan and boiled in the same manner as described above, the result being a mass of crystals suspended in a very impure mother liquor and called "Remelt Massecuite". Because of the concentration of non-sugars in the high green, the remelt massecuite is sent to a crystallizer, where it is aged and the crystallization finally finished. After the remelt massecuite has aged and cooled properly in the crystallizers, it is sent to what are known as the "brown" centrifugals, where the crystals are separated from the mother liquor. The crystals are washed, removed from the centrifugals, and dissolved in the melter. The resulting liquor, known as "melted sugar," is pumped to the blow-ups, where it is mixed with the evaporator thick juice to form blow-up thick juice, or "Thick Liquor". The mother liquor thrown off from the remelt massecuite is known as "Low Green" and is pumped out of the factory as molasses, while the syrup resulting from the washing of the crystals is called "Low Wash" and is usually taken back into the following remelt pan.

Plate No. 21 shows in a graphic manner the usual method of handling sugar end syrups.

The two final products of a beet sugar factory are granulated sugar of 100 purity and molasses, and the sugar end should be so operated that a maximum quantity of granulated sugar will be produced and a minimum amount of sugar left in the molasses. Since no non-sugars are removed in the sugar end except in the molasses. the quantity of sugar lost in the molasses depends upon the purity of the molasses, and the whole work of the sugar end becomes an effort to produce a molasses of the lowest possible purity without reducing the capacity of the factory as a whole. The importance of producing molasses of low purity may be appreciated from the fact that a reduction of one point in the purity of the molasses produced will increase the daily sugar production 22 bags in a 1,200-ton factory and 44 bags in a 2,400-ton factory.

The proper manipulation of the crystallization process and the proper management of the sugar end as a whole helps greatly toward the production of molasses of low purity. Below are a few of the more important practical points of operation which make for good sugar end work and low purity of molasses:

(1) A maximum crystallization should be secured on the white side, which means that there should be a maximum drop between the purity of the thick liquor and the high green. If this is accomplished, the amount of remelt massecuite will be reduced, more time can be used to age it in the crystallizers, and the purity of the final molasses will be lowered.

(2) The true purity of the remelt massecuite should be as low as it is possible to keep it and yet secure a massecuite that will work in the centrifugals and give a remelt sugar of high purity.

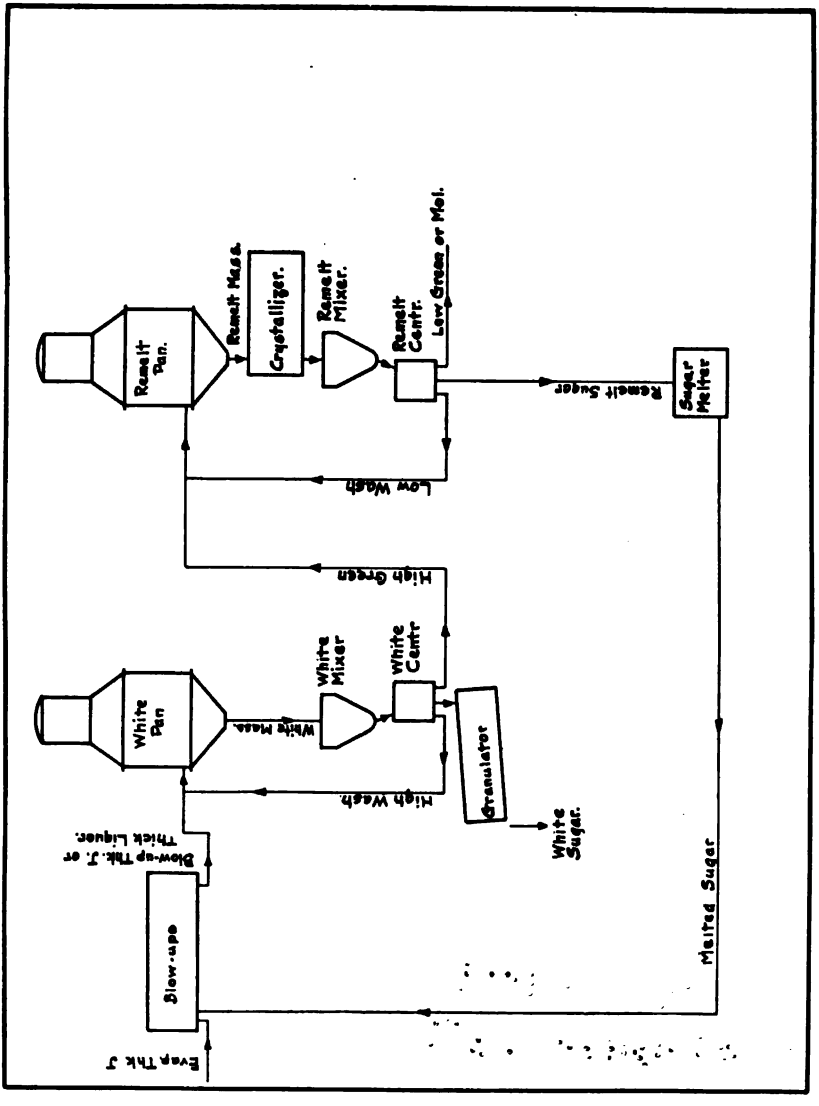
(3) The temperature of the remelt massecuite as spun should be as low as it will work properly in the centrifugals and give a remelt sugar of high purity.

(4) The time of boiling the remelt massecuite and the length of time it is aged in the crystallizers should be as long as possible. In other words, the available pans and crystallizers should be in use all of the time.

(5) Every effort should be made to produce an even grain in both the remelt and white massecuites, since this reduces the difficulty of the work on the centrifugal station and makes for better quality of white and remelt sugar.

Plate No. 21.

TYPICAL SUGAR END ARRANGEMENT



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(6) The purity of both the white and remelt massecuite should be even.

(7) Crystallizers should be well steamed out when emptied and should be thoroughly heated up before a new pan is dropped therein.

(8) The crystallizers should be cooled down evenly, and particularly at first the cooling should be slow.

(9) It is usually necessary to add some water to the crystallizers while the massecuite is cooling, but the addition of this water should be carefully controlled for if too much water is added the concentration of the massecuite will become too low and molasses of low purity will be impossible. It is better to add the water in small quantities and at frequent intervals, rather than in large quantities at less frequent intervals.

(10) Two different crystallizers should not be dumped into the mixer at the same time, as the mixture of two different massecuites increases the difficulties of the work on the centrifugals.

SECTION B

The sugar in the thick juice is separated from the impurities by taking advantage of its natural property of crystallizing from its "supersaturated" solutions. Sugar is soluble in water and its solubility increases as the temperature of the solution becomes greater. There is, however, a definite quantity of sugar which can be dissolved in a unit quantity of water at any temperature, and a solution is said to be saturated at a particular temperature when no more sugar will go into solution. Thus if sugar is added to water which is maintained at a constant temperature, and samples of the solution are taken and analyzed frequently, it will be found that the sugar content of the solution increases up to a certain point, beyond which there is no increase even though undissolved sugar is kept in contact with the solution. When this condition is reached the solution is said to be "saturated".

The amount of sugar that a unit of water will dissolve at a definite temperature is a constant value. The Sugar Solubility Table of Herzfeld given on page 315 of "Beet Sugar Manufacture" by Claassen is here incorporated.

TABLE SHOWING THE SOLUBILITY OF SUGAR IN WATER AT DIFFERENT TEMPERATURES

(Recalculated from Herzfeld, Deutsche Vereinszeitschrift, 1892, p. 181.)

One part of water will dissolve

Temperature C°	Parts of Sugar	Temperature C°	Parts of Sugar	Temperature C°	Parts of Sugar	Temperature C°	Parts of Sugar
0	1.79						
1	1.80	26	2.12	51	2.62	76	3.44
2	1.81	27	2.14	52	2.65	77	3.48
3	1.82	28	2.16	53	2.67	78	3.52
4	1.83	29	2.17	54	2.70	79	3.57
5	1.84	30	2.19	55	2.73	80	3.62
6	1.86	31	2.21	56	2.75	81	3.66
7	1.87	32	2.23	57	2.78	82	3.71
8	1.88	33	2.25	58	2.81	83	3.76
9	1.89	34	2.27	59	2.84	84	3.81
10	1.90	35	2.29	60	2.87	85	3.86
11	1.91	36	2.30	61	2.90	86	3.92
12	1.92	37	2.32	62	2.93	87	3.98
13	1.94	38	2.34	63	2.96	88	4.03
14	1.96	39	2.36	64	2.99	89	4.09
15	1.97	40	2.38	65	3.03	90	4.15
16	1.98	41	2.40	66	3.06	91	4.21
17	1.99	42	2.42	67	3.09	92	4.28
18	2.01	43	2.44	68	3.13	93	4.33
19	2.02	44	2.46	69	3.16	94	4.42
20	2.04	45	2.48	70	3.20	95	4.48
21	2.05	46	2.51	71	3.24	96	4.55
22	2.07	47	2.53	72	3.28	97	4.63
23	2.08	48	2.55	73	3.31	98	4.71
24	2.09	49	2.58	74	3.35	99	4.79
25	2.11	50	2.60	75	3.40	100	4.87

A saturated sugar solution, if the temperature is kept constant and no water is added or evaporated, will undergo no change upon standing, that is, no more sugar will be dissolved and no sugar will crystallize out. If, therefore, it is desired to crystallize out any of the sugar contained in the solution, it will be necessary either to reduce the temperature or to remove some of the water by evaporation.

A saturated sugar solution at 70° C. will contain 3.20 parts of sugar, while at 80° C. a saturated sugar solution will contain 3.62 parts of sugar to one part of water. However, a sugar solution which is saturated at 80° C. may by careful manipulation be cooled down to 70° C. without any of the sugar crystallizing out. Under such a condition each part of water at 70° C. holds in solution more than enough sugar to saturate it, and the solution is said to be "supersaturated". The amount of the supersaturation of a sugar solution may be expressed mathematically by dividing the parts of sugar actually held in solution in one part of water by the parts of sugar needed to saturate one part of water at the observed temperature, and the ratio is called the "supersaturation coefficient". Thus in the above example the "supersaturation coefficient" is $3.62 \div 3.20 = 1.13$. Any jar or agitation of a supersaturated sugar solution will cause a separation of sugar crystals, until the saturation point is reached.

The above discussion of saturation and supersaturation has been confined to pure sugar solutions, while the beet juices handled in ordinary factory practice contain non-sugars as well as sugar in solution. In these impure solutions more sugar is dissolved per part of water at any observed temperature than is possible in pure sugar solutions, and if crystallization is desired from an impure solution, the solution must be brought to a more supersaturated condition. As the concentration of non-sugars increases, the amount of sugar that one part of water will hold in solution increases, until a point is reached where no more sugar will crystallize out regardless of the concentration or supersaturation of the solution. Thus ordinary molasses at 40° C. contains 51.0 per cent sugar, 34.0 per cent non-sugars, and 15.0 per cent water, or each part of water holds in solution 3.40 parts of sugar, while in a pure sugar solution at 40° C., one part of water will hold in solution only 2.38 parts of sugar. The ratio of the parts of sugar per part of water dissolved in a saturated impure sugar solution to the parts of sugar per part of water in a saturated solution of pure sugar at the same temperature is known as the "saturation coefficient" of the solution. In the case of the molasses of the composition just described, the "saturation coefficient" is $3.40 \div 2.38 = 1.43$.

The supersaturation of an impure sugar solution at any given temperature is measured by the amount of sugar actually in solution, as compared with the amount of sugar which can be held in solution at the same temperature when the impure solution is exactly saturated, and neither undersaturated nor supersaturated.

For example, if the liquor from a boiling pan at 80° C. contains in solution 5.62 parts of sugar per part of water, and liquor of the same purity and composition at 80° C. is found to contain 4.75 parts of sugar per part of water when it is exactly saturated and not supersaturated, the "saturation coefficient" of the liquor (at 80° C.) is $4.75 \div 3.62 = 1.31$, and the "supersaturation coefficient" (at 80° C.) is $5.62 \div 4.75 = 1.18$.

Theories regarding the phenomena of solutions have been highly developed, but it would take us too deeply into physical chemistry to discuss them here. The following is given as an analogy to aid the understanding of saturation and supersaturation, rather than as a theory of what actually takes place.

All substances, solid, liquid or gaseous, consist of an indefinitely great number of small particles, and it may be considered that the particles of sugar in a sugar solution are held between the particles of water. The solution may for convenience be considered as saturated when all the spaces between the particles of water are completely filled with particles of sugar in such a way that no two particles of sugar are in contact with each other. This may be compared to the condition existing if, to a bottle partly full of buckshot, a certain quantity of fine shot is added, and the whole is well shaken up. The fine shot will fit in between the adjoining buckshot up to a certain point, beyond which a further addition of fine shot will bring about a separation of some of the fine shot into a separate mass entirely distinct from the mixture. If we stop adding fine shot at just the point where all of it is absorbed between the spaces of the buckshot, we have a saturated condition.

The influence of cooling on supersaturation may be illustrated by assuming that the cooling contracts the solution and brings the particles closer together in such a manner that the particles of sugar are squeezed between the particles of water. If the squeezing is slow and uniform, there will be no separation, but, if accompanied by agitation or shock, some of the sugar particles will slip out from between the water particles, and, when two or more of these particles come in contact, a sugar crystal is born and crystallization begins.

It has previously been stated that, in impure sugar solutions, no crystallization is possible until the solution becomes supersaturated, or, in other words, that it is harder to crystallize out sugar from impure solutions than from pure sugar solutions. It is obvious that the non-sugars present are responsible for the increased solubility of the sugar, and, if it is desired to continue with the

illustration given above, we may assume that the particles of non-sugars act toward sugar particles in the same way as water particles, that is, sugar particles are separated from each other by both water particles and non-sugar particles. Thus the total number of separating or insulating particles is increased by the impurities, the chance of two sugar particles touching each other is reduced and more sugar can be added to the solution than would be the case if no non-sugars were present.

A widely accepted theory regarding the increased solubility of sugar in impure solutions was advanced by Prinsen Geerligs and is known as the Geerligs theory of molasses formation.

In this theory it is assumed that the impurities and the sugar unite in the formation of a "sugar-salt", which is a definite chemical compound of great solubility, and from which it is impossible to crystallize the sugar. If this theory is correct, in the case of 90 purity thick juice the 10 parts of non-sugars and 90 parts of sugar would be divided as follows:

Crystallizable Sugar—75 parts.

Sugar-Salt Compound—15 parts sugar; 10 parts non-sugars.

Thus, in thick juice of 90 purity, only 83.3 per cent of the sugar can be crystallized out, and the remainder of the sugar is so combined with the non-sugars as a sugar-salt compound that it is impossible to remove it by crystallization.

Since it is assumed that the thick juice delivered to the pan floor has been purified to as great an extent as possible, the work of the sugar end becomes that of separating this thick juice into the final products, granulated sugar and molasses. This is accomplished by crystallization, and the entire crystallization process should be carried on with the purpose in mind to secure a maximum production of granulated sugar of high quality, and to produce a molasses of the lowest possible purity.

The practical application of crystallization in a sugar factory takes place in the vacuum pans. A quantity of thick juice at a density somewhat less than that of saturation is taken into the pan, and evaporation of the water is begun.

As the water is removed, the solution becomes saturated, and then supersaturated, and when the supersaturation reaches a certain point, crystallization begins. The crystals are at first so small that they are invisible to the eye, but they may be easily seen with the aid of a microscope and their gradual development watched. As the evaporation of the water is continued, more and more crys-

tals are formed until the point is reached where, in the judgment of the sugar boiler, a sufficient number of crystals have been formed to give at the end of the boiling the proper quantity of sugar crystals of the desired size. When the proper number of crystals have been formed, the further formation of crystals must be prevented by reducing the supersaturation, and this is accomplished by the addition of more syrup and by raising the temperature of the boiling mass. The supersaturation is not completely destroyed, but is only reduced to such a point that no new crystals will be formed and yet those crystals already formed will continue to grow.

The evenness in size of the final sugar will depend to a large extent on the length of the graining period, since it is obvious that those crystals formed during the first part of the graining period will immediately begin to grow and will be larger than those formed during the last part of this period. Therefore, the shorter the time which elapses between the appearance of the first crystals and the last crystals, and the shorter the time taken to stop the formation of more crystals, the more even in size the resulting sugar will be. A long graining period not only tends toward the production of sugar of uneven size, but also during a long graining period there is a tendency for the smaller crystals to attach themselves to the nearest large crystal and form bunches. This results in a final sugar of abnormal shape and of poor color. The use f the "seeding" method of graining considerably reduces the length of the period of graining, and tends toward the production of even sized sugar.

After the grain has been formed, the concentration of the massecuite during the rest of the boiling period is kept at such a point that no new crystals will form, and yet those crystals already formed will continue to grow.

The ideal condition for crystal growth during the growing period is that where the supersaturation of the mother liquor is at all times constant. Under such a condition, the forces tending to cause the growth of the crystals is constant at all times, and the final crystals formed will be of normal shape, hard, and easy to purge and wash in the centrifugals. To maintain the proper condition of concentration for crystal growth, new quantities of the syrup being boiled are more or less continuously drawn into the pan, the water therein contained is continuously removed by evaporation, and the sugar crystallized upon the crystals already present. The syrup introduced contains not only sugar and water, but also certain non-sugars, with the result that, as the evaporation

and crystallization continues, there is a gradual decrease in the purity of the mother liquor, and, as the purity of the mother liquor decreases, the rate of crystallization also decreases. Because of the decrease in the purity of the mother liquor as the crystallization proceeds, the boiling massecuite is maintained at a higher concentration, or "tighter together", during the latter part of the boiling or growing period than during the earlier part of this period.

The addition of the new syrup to the pan may be done in either of two ways, that is, it may be introduced intermittently "by drinks", or it may be added continuously by a "set valve". If the syrup is added by "drinks", the massecuite is brought quite "close together", then "lossened up" with a "drink" of new syrup, again brought together, and loosened up, and so on during the course of the entire boiling. The disadvantage of this method lies in the fact that the forces working toward crystallization are not kept constant. Thus after each "drink" the supersaturation is reduced to a low degree, the growth of the crystal stops, and even some dissolving action may take place, while, when the mass is very close together just before the drink, the supersaturation is high, and new grains may be formed which will tend to bunch together and cause the formation of soft grain.

If, however, the pan is boiled on "set valve", new syrup is added continuously, the concentration and supersaturation is kept constant, with a gradual increase toward the end of the boiling period, with the result that the forces of crystallization are at all times constant.

Good sugar may be boiled by either the "drink" method or the "set valve" method, but the "drink" method requires greater skill and watchfulness on the part of the sugar boiler than does the "set valve" method.

There is a limit to which the concentration and its resulting crystallization can be carried and this is determined by the fluidity of the massecuite, that is, the concentration must be stopped short of the point at which the massecuite will not flow from the pan or "pick up" in the centrifugal machines. There are various conditions influencing the fluidity which may reduce the crystallization below what it should be. For example, if the grains be very uneven in size or very fine, the limit of fluidity will be reached sooner than if the grains be uniform and of a larger size; also if the purity of the mother liquor be very low, the presence of the non-sugars will reduce the fluidity by making the crystals stick more closely together.

In ordinary sugar factory work the following liquors and syrups are used in boiling white massecuite: thick juice and melted sugar, high wash, and high green: and they should be added to the pan in the order of decreasing purity. Thus the charge and first part of the boiling syrup should be thick juice and melted sugar, the next part of the boiling syrup should be high wash, and the pan should be finished off with high green. In the boiling of remelt massecuite two syrups, high green and low wash, are ordinarily used, and in this case the high green is used first and the pan is finished off with low wash.

The principles outlined in the above apply equally to the boiling of white or remelt massecuite, but, because of the greater concentration of non-sugars in the remelt massecuite than in the white massecuite, the crystallization is slower and the extent to which it can be carried is more limited. Thus the practical limit of crystallization is reached in white massecuite after about three hours boiling, while, in the case of remelt massecuite, between 48 and 72 hours are needed for complete crystallization. In the same way the practical limit of crystallization for remelt massecuite is usually reached when 40 per cent of the dry substance of the massecuite has been crystallized out as sugar, as compared with 50 per cent crystallization in the case of white massecuite.

The slowness of the crystallization of the remelt massecuite makes it necessary to have either a very great pan capacity where the remelt massecuite can be boiled for the needed time, or to take the massecuite from the pan and allow it to age and cool in crystallizers for the necessary length of time. At most factories crystallizers are provided, but at a few factories Grosse pans are used.

The temperatures at which the pan is grained and boiled are not entirely standardized. As a general proposition, both the white and remelt pans are grained at a low temperature (70° C.), and after the graining the temperature is raised to 85° C. to 90° C. until the grain is well set. Some operators, when boiling white massecuite, drop the temperature during the growing period, while other operators hold the pan at 80° C. to 90° during the entire growing period. The high temperature during the growing period tends toward the production of harder grain than the low temperature. When boiling remelt massecuite, from 75° C. to 80° C. seems to be the best temperature for the growing period.

PROBLEMS

Example

Assume that it is desired to boil a pan of 87.5 purity and that there is available 1,200 cu. ft. of thick juice at 68 Brix and 91.0 purity, and 700 cu. ft. of high wash syrup at 70 Brix and 88.0 purity. How many cu. ft. of high green syrup will be required at 72 Brix and 77.0 purity to make the massecuite of the above purity?

Let Vt = Volume of Thick Juice ..... = 1,200
Vw = Volume of High Wash Syrup ..... = 700
Vg = Volume of High Green Syrup .....
Pm = Purity of Massecuite ..... = 87.5
Pt = Purity of Thick Juice ..... = 91.0
Pw = Purity of High Wash Syrup ..... = 88.0
Pg = Purity of High Green Syrup ..... = 77.0
Bt = Brix of Thick Juice ..... = 68
Bw = Brix of High Wash Syrup ..... = 70
Bg = Brix of High Green Syrup ..... = 72

$$Vg = \frac{Vt\ Pt\ Bt + Vw\ Pw\ Bw - (Vt\ Bt + Vw\ Bw)\ Pm}{Bg\ Pm - Pg\ Bg}$$

$$= \frac{1{,}200 \times 91 \times 68 + 700 \times 88 \times 70 - (1{,}200 \times 68 + 700 \times 70)}{72 \times 87.5 - 77 \times 72}$$

$$\frac{87.5}{} = \frac{7{,}245{,}600 + 4{,}312{,}000 - (81{,}600 + 49{,}000)\ 87.5}{6{,}300 - 5{,}540} = \frac{7{,}425,\cdot}{}$$

$$\frac{600 + 4{,}312{,}000 - 11{,}427{,}500}{756} = \frac{310{,}100}{756} = 410.$$

Since the Brix of the juices used on the pan floor is reasonably uniform, it is generally sufficiently accurate to disregard the Brix, in which case the formula can be reduced to the following:

$$Vg = \frac{Vt\ Pt + Vw\ Pw - (Vt + Vw)\ Pm}{Pm - Pg} =$$

$$\frac{1{,}200 \times 91 + 700 \times 88 - (1{,}200 + 700)\ 87.5}{87.5 - 77} =$$

$$\frac{109{,}200 + 61{,}600 - 166{,}250}{10.5} = \frac{4{,}550}{10.5} = 433.$$

(1) Assume that it is desired to boil a white pan of 86.5 purity. There is 1,200 cu. ft. of thick juice of 90.0 purity, and 700 cu. ft. of high wash syrup of 85.0 purity, that are to be used in this pan; how many cubic feet of high green syrup of 77.4 purity should be used to obtain a massecuite of the above purity?

Example

Assume that a raw pan when finished will contain 1,200 cu. ft. of raw massecuite of 95.0 Brix and 75.0 purity. How many cubic feet of high green at 70.0 Brix and 78.0 purity, and how many cubic feet of low wash at 68.0 brix and 65.0 purity will be needed to make up the above massecuite?

Vm = Volume of Massecuite ..... = 1,200
Vg = Volume of green syrup.
Vw = Volume of wash syrup.
Pm = Purity of massecuite ..... = 75.0
Pg = Purity of green syrup ..... = 78.0
Pw = Purity of wash syrup ..... = 65.0
Bm = Brix of massecuite ..... = 95.0
Bg = Purity of green syrup ..... = 70.0
Bw = Brix of wash syrup ..... = 68.0

$$Vg = \frac{Vm\ Bm\ (Pm - Pw)}{Bg\ (Pg - Pw)} = \frac{1{,}200 \times 95\ (75.0 - 65.0)}{70\ (78.0 - 65.0)} =$$

$$\frac{114{,}000 \times 10}{70 \times 13} = \frac{1{,}140{,}000}{91} = 1{,}253 \text{ cubic feet.}$$

$$Vw = \frac{Vm\ Pm\ (Pg - Pm)}{Bw\ (Pg - Pw)} = \frac{1{,}200 \times 95\ (78.0 - 75.0)}{68\ (78.0 - 65.0)} =$$

$$\frac{114{,}000 \times 3}{68 \times 13} = \frac{342{,}000}{884} = 387 \text{ cubic feet.}$$

(2) If it is desired to boil a pan of 1,150 cubic feet of raw massecuite of 96.5 Brix and 74.0 purity, how many cubic feet of high green of 78.0 purity and 71.0 Brix, and how many cubic feet of low wash of 65.0 purity and 69 Brix will be needed?

CHAPTER NO. VIII

SUGAR END MANAGEMENT

As stated in the lecture on Crystallization, the work of the sugar end consists in separating the thick juice delivered to it into the two final products, granulated sugar and molasses. The thick juice delivered to the sugar end has been treated and purified to as great an extent as possible and contains a minimum quantity of non-sugars, and, since no non-sugars are eliminated by the sugar end treatment, except in the molasses, the amount of sugar recovered as granulated sugar and the amount of sugar left in the molasses, disregarding losses, will depend entirely upon the *purity* of the molasses produced. The lower the purity of the final molasses produced, the greater the quantity of granulated sugar that will be recovered, or, in other words, the entire work and effort of the sugar end should be concentrated on securing a final molasses of the lowest possible purity without reducing the capacity of the factory as a whole.

As a general proposition each factory has a certain beet end capacity, and it is necessary to manage the sugar end so that it does not delay the factory, and yet the molasses is reduced to as low a purity as is possible with the equipment provided. It is accordingly impossible to lay down any hard and fast rules of sugar end management, but the plan of operation must needs be different for each particular factory, and for beets of varying quality. There are, however, some general principles which apply to every factory, and a thorough appreciation of them is necessary for intelligent sugar end management. Every pound of sugar and every pound of non-sugar in the thick juice must finally be sent out as granulated sugar or as molasses, and, unless each day's operation shows that approximately as much sugar and non-sugar is being taken out of the house as is entering it, the factory is filling up and trouble is ahead. This matter should be watched carefully day by day, and, if the factory is filling up, the plan of operation in relation to the purities and concentrations of massecuites should be changed.

For a given factory and campaign, the limiting conditions of operation are the purity of the thick juice and the purity to which it is agreed the molasses may be reduced. The practical limit of crystallization on the white side is 45 to 50 per cent, and on the raw side is 35 to 40 per cent, and, by using these percentages, and a known or assumed purity for the various products, it is possible

to calculate the relative amounts of all the products. The quantities of the different products thus calculated may be compared with the known capacity of the apparatus and the time available for the operation, and in this way the best procedure to be followed can be determined.

To illustrate the application of the above, a calculation will be given, in which the relative amount of each product is based on 100 parts of thick juice dry substance, and on beets.

Weight of Evaporator Thick Juice Dry Substance.... = 100.0 A

Purity of Evaporator Thick Juice ..... = 90.0 B

Purity of Molasses Produced ..... = 60.0 C

Weight of Granulated Sugar

$$\frac{B-C}{100-C} \times 100 = \frac{90-60}{100-60} \times 100 \ldots\ldots = 75.0 \quad D$$

Weight of Dry Substance of Molasses Produced

$= A - D = 100.0 - 75.0$ ..... = 25.0 E

Weight of Sug. in Molasses Produced

$$\frac{E \times C}{100} = \frac{60 \times 25}{100} \ldots\ldots = 15.0 \quad F$$

Per Cent Crystallization from Remelt Massecuite..... = 40.0 G

Purity of Remelt Massecuite

$$\frac{G\,(100-C)}{100} + C = \frac{40\,(100-60)}{100} + 60 \ldots\ldots = 40.0 \quad H$$

Purity of Unwashed Remelt Sugar..... = 92.0 I

Weight of Unwashed Raw Sugar, % on Remelt Mass.

Dry Sub. $\frac{H-C}{I-C} \times 100 = \frac{76-60}{92-60} \times 100$..... = 50.0 J

Weight of Molasses Produced, % on Remelt Massecuite Dry Substance $= 100 - J = 100 - 50$..... = 50.0 K

Purity of Washed Remelt Sugar ..... = 98.0 L

Purity of Low Wash..... = 65.0 M

Weight of Washed Remelt Sugar, % on Remelt Mass. =.....

$$\frac{I-M}{L-M} \times J = \frac{92-65}{98-65} \times 50 \ldots\ldots = 40.9 \quad N$$

Weight of Low Wash, % on Remelt Massecuite $= J - N = 50.0 - 40.9$ ..... = 9.1 O

Weight of Remelt Massecuite, % on Thick Juice Dry Sub. =

$$\frac{E}{K} \times 100 \quad \frac{25}{50} \times 100 \ldots\ldots = 50.00 \quad P$$

Weight of Washed Remelt Sugar, % on Thick Juice

Dry Sub. $\frac{N \times P}{100} = \frac{40.9 \times 50.0}{100}$ ..... = 20.45 Q

Weight of Low Wash, % on Thick Juice Dry Sub. =

$$\frac{O \times P}{100} = \frac{9.1 \times 50.0}{100} = 4.55 \quad R$$

Weight of Molasses, % on Thick Juice Dry Sub. =

$$\frac{K \times P}{100} = \frac{50.0 \times 50.0}{100} = 25.00 \quad S$$

Weight of High Green to make up Remelt Massecuite, % on Remelt Massecuite, Dry Substance =

$$100 - 0 = 100 - 9.1 = 90.0 \quad T$$

Purity of High Green used in Remelt Massecuite =

$$\frac{100\,H - OM}{T} = \frac{100\,(76) - 9.1\,(65)}{90.9} = 77.1 \quad U$$

Per Cent Crystallization from White Massecuite = 50.0 G_1

Purity of White Massecuite =

$$\frac{G_1\,(100 - U) + U}{100} = \frac{50\,(100 - 77.1) + 77.1}{100} = 88.55 \quad H_1$$

Weight of Pan Floor Thick Juice, % on Dry Sub. Evaporator Thick Juice = $A + Q = 100 + 20.45$ = 120.45 A_1

Purity of Pan Floor Thick Juice =

$$\frac{AB + QL}{A + Q} = \frac{100\,(90) + 20.45\,(98)}{100 + 20.45} = 91.3 \quad B_1$$

Purity of High Wash = 88.55 M_1

Purity of Unwashed White Sugar = 97.0 I_1

Purity of Washed White Sugar = 100.0 L_1

Weight of Unwashed Sugar, % on Dry Sub. White Massecuite

$$= \frac{(H_1 - U)}{(I_1 - U)} \times 100 = \frac{(88.55 - 77.1)}{(97.0 - 77.1)} \times 100 = 57.5 \quad J_1$$

Weight of High Green, % on Dry Sub. White Mass. $= 100 - J_1 = 100 - 57.5$ = 42.5 K_1

Weight of Sugar in Unwashed Sugar, % on White Massecuite

$$= \frac{(J_1 \times I_1)}{100} = \frac{57.5 \times 97}{100} = 55.78 \quad V$$

Weight of Non-Sugar in Unwashed Sugar, % on White Massecuite $= J_1 - V = 57.5 - 55.78$ = 1.72 W

Weight of High Green in Unwashed White Sugar, % on White Massecuite =

$$\frac{W}{100 - U} \times 100 = \frac{1.72}{100 - 77.1} \times 100 = 7.5 \quad X$$

Weight of White Sugar in High Wash, % on White Massecuite

$$= \frac{X\,(M_1 - U)}{100 - M_1} = \frac{7.5\,(88.55 - 77.1)}{100 - 88.55} = 7.5 \quad Y$$

PRODUCTS OF WHITE MASSECUITE, % ON DRY SUBSTANCE OF WHITE MASSECUITE

Total Weight of High Wash of 88.55 Purity, % on White Massecuite $= X + Y = 7.5 + 7.5$	= 15.0	O_1
Total Weight of Washed Sugar of 100 Purity, % on White Massecuite $= J_1 - O_1 = 57.5 - 15.0$	= 42.5	N_1
Total Weight Green Syrup of 77.1 Purity, % on White Massecuite	= 42.5	K_1
Total	100.0	

COMPOSITION OF WHITE MASSECUITE, % ON DRY SUBSTANCE WHITE MASSECUITE

Weight of High Wash	= 15.0	O_1
Weight of Pan Floor Thick Juice $= \frac{O_1 (U - M_1) + 100 (M_1 - U)}{B_1 - U} = \frac{15.0 (77.1 - 88.55) + 100 (88.55 - 77.1)}{91.3 - 77.1}$	= 68.5	Z
Weight of High Green $= 100 - O_1 - Z = 100 - 15.0 - 68.5$	= 16.5	Z_1
Total	100.0	

Weight of White Massecuite, % on Evaporator Thick Juice, Dry Substance $= \frac{A_1 \times 100}{Z} = \frac{120.45 \times 100}{68.5} = 175.9$ P_1

WEIGHT OF DRY SUBSTANCE OF SUGAR END PRODUCTS PRODUCED % ON EVAPORATOR THICK JUICE DRY SUBSTANCE

Weight of Molasses Produced	= 25.0	S
Weight of Low Wash	= 4.55	R
Weight of Remelt Sugar	= 20.45	Q
Weight of Remelt Massecuite	= 50.0	P
Weight of White Sugar $= \frac{N_1 \times P_1}{100} = \frac{42.5 \times 175.9}{100}$	= 74.8	Q_2
Weight of High Wash $= \frac{O_1 \times P_1}{100} = \frac{15.0 \times 175.9}{100}$	= 26.4	R_1
Weight of High Green $= \frac{K_1 \times P_1}{100} = \frac{42.5 \times 175.9}{100}$	= 74.8	S_1
Per Cent Sugar in Cosettes	= 16.00	B_2
Sugar in Molasses Worked, % on Beets	= 3.50	C_2
Sugar Lost in Pulp and Pulp Water, % on Beets	= .30	D_2
Sugar Lost in Lime Cake, % on Beets	= .10	E_2
Sugar Lost in Steffen Waste, % on Beets	= .10	F_2
Sugar Lost in Unknown	= .20	G_2

Sugar in Evaporator Thick Juice, % on Beets $= B_2 + C_2 - D_2 - E_2 - F_2 - G_2 = 16.00 + 3.50 - .30 - .10 - .10 - .20$ ..... $= 18.80$ F_3

Purity of Evaporator Thick Juice ..... $= 90.0$ B

Dry Substance of Evaporator Thick Juice, % on Beets =

$$\frac{F_3}{B} \times 100 = \frac{18.80}{90} \times 100 \text{ ..... } = 20.89 \quad G_3$$

DRY SUBSTANCE SUGAR END PRODUCTS, % ON BEETS

Molasses Produced $= \frac{S \times G_3}{100} = \frac{25.0 \times 20.89}{100} =$ 5.22 H_3

Weight of Low Wash $= \frac{R \times G_3}{100} = \frac{4.55 \times 20.89}{100} =$ .95 I_3

Weight of Remelt Sugar = $\frac{Q \times G_3}{100} = \frac{20.45 \times 20.89}{100}$ ..... $= 4.27$ J_3

Weight of Remelt Massecuite = $\frac{P \times G_3}{100} = \frac{50.0 \times 20.89}{100}$ ..... $= 10.4$ K_3

Weight of White Sugar = $\frac{Q_2 \times G_3}{100} = \frac{74.8 \times 20.89}{100}$ ..... $= 15.63$ L_3

Weight of High Wash = $\frac{R_1 \times G_3}{100} = \frac{26.4 \times 20.89}{100}$ ..... $= 5.51$ M_3

Weight of High Green = $\frac{S_1 \times G_3}{100} = \frac{74.8 \times 20.89}{100}$ ..... $= 15.63$ N_3

Weight of White Massecuite = $\frac{P_1 \times G_3}{100} = \frac{175.9 \times 20.89}{100}$ ..... $= 36.75$ O_3

Weight of Pan Floor Thick Juice = $\frac{A_1 \times G_3}{100} = \frac{120.45 \times 20.89}{100}$ ..... $= 25.16$ Q_3

The above calculation gives the amount of products to be handled for one set of conditions only, and, by using different purities and different yields for crystallization, any number of such calculations can be made. Every operator who is going to manage a sugar end should make for himself several calculations such as the above with different combinations of purity, crystallization yields, etc., and then, from the quantities of sugar end products to be handled and the equipment available, he can determine the

time that is at disposal for each operation, such as boiling white massecuite, spinning white and remelt massecuite, boiling remelt massecuite, ageing remelt massecuite in the crystallizers, etc., and so decide for himself the best line of procedure to follow.

The quantity of materials to be handled does not of course tell the whole story in sugar end management, but an understanding of such quantities will often be of great help. Thus, if it is desired to make any change in the sugar end management such as lowering the purity of the remelt massecuite, a calculation like the above may show that, with the equipment available, such a change is not advisable and future trouble may be avoided.

Several fundamental factors influence the purity of the final molasses, among which may be mentioned the following:

(1) A maximum amount of crystallization should be done on the white side, which means that there should be as large a drop as possible between the purity of the thick juice and the purity of the high green.

If this is done, less low wash will be needed in the remelt massecuite, the quantity of remelt massecuite to be boiled will be reduced, each crystallizer may be aged longer, and the purity of the molasses will be decreased. To lower the purity of the high green, it is necessary to reduce the purity of the white massecuite, which means that more high green must be used in the white pans. There is also a relation between the purity of the white massecuite and the color of the granulated sugar, and this factor likewise often influences the point to which the purity of the white massecuite can be reduced.

(2) There is a general relation between the purity of the remelt massecuite and the purity of the final molasses, and, within certain limits, the lower the purity of the massecuite, the lower will be the purity of the molasses produced. To obtain massecuite of low purity, it is necessary either to produce high green of low purity or use large quantities of low wash. The purity of the high green is governed by the white side work as explained above, while the use of large quantities of low wash materially increases the quantity of remelt massecuite to be handled, and may, by reduction in the time of boiling and in the time in crystallizers, actually increase the purity of the molasses. As a general proposition, the purity of the high green should be so regulated that all the low wash can be used to give a remelt massecuite of the desired purity, but at no time should the low wash be supplemented by molasses for the purpose of reducing the purity of the remelt massecuite,

for this procedure so increases the quantity of massecuite that ordinarily it cannot be handled properly with the equipment available, the purity of the raw sugar will be low, and the whole sugar end will soon be in a state of chaos. At times it is even advisable to discard some of the low wash to help clean out the sugar end. As remelt massecuite of low purity is usually very viscous and increases the difficulty of securing a high grade of remelt sugar, this to a certain degree limits the extent to which the purity can be reduced. The above may all be summarized in the statement that the purity of the remelt massecuite should be as low as possible, and yet allow the proper time for boiling and ageing in the crystallizers with the equipment available and permit the production of a high grade of remelt sugar.

(3) The lower the temperature of the remelt massecuite as spun, the greater will be the crystallization, and the lower will be the purity of the molasses produced. How far this temperature can be reduced is determined by the point where the massecuite will still be of sufficient fluidity to work well in the centrifugals and allow the production of remelt sugar of high quality.

(4) Long time of boiling in the pans and long time of ageing in the crystallizers tend toward the production of low purity molasses. In other words, the pan and crystallizer capacity at every factory should be in use all of the time.

(5) The supersaturation or density of the remelt massecuite, during its time in the crystallizer and at the time it is spun, greatly influences the extent to which the crystallization can be carried. If this concentration is too high, the crystallization may be retarded by the great viscosity, false grain may form, or the fluidity of the massecuite may be such that it will not work well in the centrifugals. As a massecuite cools the supersaturation and viscosity increases, and to keep these factors within reasonable limits it is uusally necessary to add water to the crystallizers during the cooling process. The only way we have at present to control the addition of this water is by observation of the massecuite and though our practical sugar end foremen become very expert in their judgment of the need of water, yet this method is very crude and often not enough water or too much water is added. If too little water is added, the crystallization is retarded and the molasses is not exhausted to as low a point as it should be, while if too much water is added, some of the sugar already crystallized will be dissolved and molasses of low purity will be impossible. We are in need of better control on crystallizer work.

(6) The purity of the remelt sugar should be as high as possible. If the purity of the remelt sugar is low, non-sugars therein contained, instead of going out with the molasses, are sent back to the white pan and the total quantity of massecuite to be handled will be increased.

In sugar end management it is important that clean cut separations be made between each product, and that after the separation there be no opportunity for mixing the products. The separation of the products is made at the centrifugals; at the white centrifugals white sugar, high green, and high wash are separated from each other, while at the remelt centrifugals remelt sugar, molasses, or low green, and low wash are separated. A poor separation or a mixture of the white side products makes for uneven work, for, in the case of high wash being mixed with the high green which is sent to the remelt side, the purity of the high green is increased and the crystallization is decreased, while on the remelt side the mixture of low green with low wash will increase the quantity of remelt massecuite, and the mixture of low wash with low green will increase the purity of the low green, or molasses. A more extended discussion of the question of separation will be given in the lecture on Centrifugal work.

Even purity of both the white and the remelt massecuite makes for good and regular sugar end work, and every effort should be used to keep these purities uniform.

Where high green is used in the white pans, it is good practice to use only high green from those white pans in which no high green has been used. Thus one pan is boiled from Thick Liquor and High Wash, and the green syrup from this so-called "straight" pan is used in the two or three succeeding pans, the green syrup from these pans being sent to the remelt side. This practice prevents a continual inboiling of green syrup and is usually helpful in securing a good colored final product.

The quality of the final product, the granulated sugar, is all important and the operator should lend every effort toward securing a product of the highest quality. Many factors influence the quality of the sugar produced, among which may be mentioned:

(1) The thick liquor should be well sulphured and thoroughly filtered. In a great many cases it is advisable to add lime to the melted sugar before mixing it with the thick juice in the blow-ups, since this method of treatment increases the amount of sulphuring that is possible and generally improves the color of the thick liquor.

(2) The high wash and high green syrups used in the white pans should be thoroughly filtered. Also, if the equipment is available, treatment of these syrups with sulphur dioxide gas is advantageous.

(3) The remelt sugar should be of as high quality as possible, for, as a general rule, the better the quality of the remelt sugar, the better is the quality of the white sugar.

(4) The color of the sugar will suffer if the purity of the white massecuite is too low or if the work in the pans does not give an even grain of hard texture.

(5) Good and careful centrifugal work is absolutely essential to the production of sugar of high quality. It is believed by most observers that three-fourths of off-color sugar is due to inferior work on the centrifugals.

PROBLEMS

Examples.

Consider that we have a white pan massecuite of 87 purity and the High Green Syrup from the same is 77 purity, what per cent of the dry substance in the massecuite is crystallized?

Let Pm = Purity of Massecuite ..... = 87.0
Pg = Purity of High Green Syrup ..... = 77.0
C = Per cent Crystallization on Dry Substance in Massecuite.

$$C = \frac{(Pm - Pg)}{(100 - Pg)} \times 100 = \frac{(87.0 - 77.0)}{(100 - 77)} \times 100 = \frac{(10)}{(23)} \times 100 = \frac{1000}{23} \quad \ldots\ldots = 43.5$$

A pan holds 1,600 cubic feet of massecuite containing 90 per cent dry substance, and one cubic foot of massecuite weighs 92 pounds. How many pounds of sugar will be crystallized under the conditions given above?

Let V = Volume of massecuite ..... = 1,600
W = Weight of one cubic foot of massecuite ..... = 92
D = Per cent Dry Substance of massecuite ..... = 90
R = Pounds of Dry Substance in massecuite.

$$R = \frac{V \times W \times D}{100} = \frac{1600 \times 92 \times 90}{100} = \frac{13{,}248{,}000}{100} = 132{,}480$$

C = Per cent Crystallization on Dry Substance in Massecuite ..... = 43.5
X = Pounds of Sugar Crystallized.

$$X = \frac{R \times C}{100} = \frac{132{,}480 \times 43.5}{100} = \frac{5{,}762{,}880}{100} = 57{,}628 \text{ pounds,}$$

or 576 bags.

(1) Consider that we have a white pan of 1,630 cubic feet of massecuite weighing 92 pounds per cubic foot, of 90 per cent dry substance and 87.5 purity. What percentage of crystallization takes place and how many pounds of sugar are crystallized if the purity of the high green syrup is 77.5? What percentage of crystallization and how many pounds of sugar would be crystallized if the purity of the green syrup had been 76.5?

Example

As stated above, the quantity of molasses produced depends entirely upon the purity of the thick juice and the purity of the molasses. As an example, let us assume that a factory slices 1,200 tons of beets per 24 hours containing 16.00% sugar; the pulp contains .20% sugar, the pulp water contains .10% sugar and the sugar loss in lime cake is .05% on beets. How many tons of dry substance and how many tons of sugar will there be in the molasses produced, if the purity of the thick juice is 90.0 and the purity of the molasses is 60.0?

Let A = Tons Beets Cut ..... = 1,200

M = % Sugar in Beet ..... = 16.00

B = % Sugar in Pulp ..... = .20

C = % Sugar in Pulp Water ..... = .10

X = Sugar lost in Lame Cake, % on Beets ..... = .05

N = Tons Sugar in Beets =

$$\frac{A \times M}{100} = \frac{1200 \times 16}{100} = 192.00 \text{ Tons}$$

D = Tons of Sugar lost in Pulp =

$$\frac{A \times B}{100} = \frac{1200 \times .20}{100} = 2.40 \text{ Tons}$$

E = Tons Sugar lost in Pulp Water =

$$\frac{A \times C}{100} = \frac{1200 \times .10}{100} = 1.20 \text{ Tons}$$

Y = Tons Sugar lost in Lime Cake =

$$\frac{A \times X}{100} = \frac{1200 \times .05}{100} = .60 \text{ Tons}$$

K = Sugar in Thick Juice =

$$N - D - E - Y = 187.80 \text{ Tons}$$

Pt = Purity of Thick Juice ..... = 90.0

Q = Tons Dry Substance in Thick Juice =

$$\frac{K}{Pt} \times 100 = \frac{187.80}{90} \times 100 = 208.66 \text{ Tons}$$

Pm = Purity of Molasses.

G = % Sugar crystallized out, % on Dry Substance of Thick Juice.

$$G = \frac{Pt - Pm}{100 - Pm} = \frac{90 - 60}{100 - 60} \text{.....} = 75\%$$

F = Tons Sugar Crystallized out of Thick Juice

$$\frac{Q \times G}{100} = \frac{208.66 \times 75}{100} \text{.....} = 156.49 \text{ Tons}$$

H = Tons Dry Substance in Molasses = Q — F = 208.66 — 156.49..... = 52.17 Tons

J = Tons Sugar in Molasses =

$$\frac{H \times Pm}{100} = \frac{52.17 \times 60}{100} = 31.30 \text{ Tons Sugar}$$

(2) If a factory slices 123,692 tons of beets containing 16.38% sugar and the sugar in the pulp is .19%, in the pulp water .09%, the loss in the lime cake .06% on beets and the purity of the thick juice is 90.0; how many tons of sugar will be sent out in the molasses if the purity of the molasses is 60.0? How many tons of sugar will be sent out in the molasses if the purity of the molasses is 58.0? If the sugar in the form of molasses is worth 1.5c per pound, and in the form of granulated sugar at this stage of the process is worth 5c per pound, how much money will be saved by reducing the purity of the molasses from 60.0 to 58.0?

CHAPTER NO. IX

CENTRIFUGALS, GRANULATORS AND SUGAR WAREHOUSES

After the crystallization is completed in the white pan and in the crystallizers, it is necessary to separate the crystals from the surrounding syrup. This is accomplished at the centrifugal station. A centrifugal machine consists essentially of a perforated basket revolving within an iron curb. The massecuite is allowed to run into the basket and is thrown by centrifugal force against the vertical perforated screen, which retains the crystals and allows the syrup to pass out into the curb and from there to storage tanks. After the syrup is spun out, the crystals are washed by sprinkling the wall of sugar with water, which, with the accumulated impurities and some dissolved sugar, passes out as wash syrup in the same manner as the mother liquor.

The usual centrifugal station is divided into two parts, one being used for white sugar and the other for remelt sugar. Each part consists of a number of centrifugals with driving, washing and syrup separating devices. Above each row of machines is a "mixer" or storage tank, for massecuite, and below is a conveyor for handling the sugar, and troughs for the syrups.

WHITE CENTRIFUGAL STATIONS

The mixer above the white machines is usually a long "V" shaped open tank equipped with a slowly moving agitator and having a capacity sufficiently large to hold at least one full pan of white massecuite. When a strike is finished in the white pan, the agitator in the mixer is started and the contents of the pan are dropped by gravity into the white mixer. White massecuite is of such a density and purity that, if allowed to remain without agitation, it would become full of hard lumps which would make the work on the centrifugals difficult. To avoid this, the agitator is kept running as long as there is any massecuite in the mixer. During the time that the strike is being worked out the massecuite cools down to a considerable extent, and very often, by the time the mixer is nearly empty, it has become very stiff and difficult to work. To overcome this difficulty, a small amount of high green

syrup may be added to "free up" the massecuite. As the green syrup is already a saturated sugar solution, it will not dissolve any of the sugar crystals. Water should not be added to the mixer under any circumstances. As the massecuite is drawn down, some will be left adhering to the side of the mixer, which, if not removed, will become hard and will not purge or wash in the centrifugals. For this reason the mixer should be scraped down at the end of each strike.

From the mixer, the massecuite is delivered by gravity to the centrifugal machines. Before loading the machine, all of the sugar from the previous charge should have been removed from the screen, for, if this is not done, the screens will soon become partially stopped up, a portion of the sugar will not be thoroughly purged, and off-color sugar will result. If the screens become dirty, they may be cleaned by washing the empty centrifugal, while rotating, with water. Care should also be exercised to see that there are no holes in the screen large enough to allow sugar crystals to pass through with the green syrup. Sometimes the screens are too narrow for the basket, leaving an opening at the top, through which crystals will pass. The inner screen should have openings of a proper size to allow the syrup to pass out freely and still retain the sugar, and the backing up screen should be of such construction as to support the inner screen and at the same time block off as few holes as possible in the screen and in the basket.

Before any white massecuite is introduced, the centrifugal should have been started, as otherwise some of the syrup may leak through the saw plate valve into the white sugar, thereby discoloring the final product. In factory parlance, "the machine should be loaded on the run". The baskets should be filled evenly, usually with a full charge, to prevent any sugar from being overwashed. Care must be taken not to overload so that some of the massecuite goes over the top of the basket and in with the syrup. When the basket is filled, there should be an even vertical wall of sugar in the machine, or some of the sugar will be overwashed and some underwashed. If the sugar is thicker in the bottom of the machine, it is an indication that either the massecuite is too heavy for proper working or that the machine accelerates too slowly. A forty-inch diameter, belt driven centrifugal should be up to full speed one minute after the clutch is thrown in. Forty-inch diameter centrifugals on white sugar should rotate about 1,200 R. P. M.

From good white massecuite the syrup should be spun out almost by the time the centrifugal is up to speed. The ease with which the separation of the syrup from the crystals takes place depends almost entirely upon the quality of the massecuite as determined by the evenness of the crystals and the viscosity of the mother liquor. The more viscous the mother liquor, the more slowly it will be removed from the sugar. Uneven grain also slows up the centrifugal work, as the small grains fill the interstices between the larger grains and so prevent the passage of the syrup. In case of a very difficult strike it is sometimes desirable to introduce steam into the curb outside of the basket. This keeps the massecuite warm and so reduces the viscosity of the syrup.

Washing should not be started until practically all of the green syrup has been spun off. The water used for washing should be pure warm water, of 60 to 65° C. temperature. This accomplishes the best results with the smallest amount of water which will give white sugar. The question of the temperature of centrifugal wash water has received considerable attention the last few years, and experience has proven that warm water is more satisfactory than the cold water previously used. The reasons for this may be summarized as follows:

(1) A smaller quantity of water is needed.

(2) The purity of the wash syrup is lower, which shows that a smaller amount of the crystals has been dissolved.

(3) The percentage of moisture in the wet sugar discharged from the centrifugals is less, thereby reducing the work to be done by the granulators.

The probable reason for the superiority of the warm water is that the temperature of the mother liquor is raised and its viscosity thereby reduced, so that it is more easily separated from the crystals. The accompanying tabulation shows the relative effect of cold and hot wash water as used at the factories of the Great Western Sugar Company.

The wash water should be distributed evenly over the face of the sugar in the machine, if an excess of water or an off-color final product is to be avoided. An excess of water should not be thrown on the bottom of the basket, as this dissolves a large amount of sugar in this part of the machine. It is very important that sugar be thoroughly washed in the centrifugals as otherwise it will be yellow and discolor the granulated sugar. Probably three-fourths of all off-color sugar results from poor centrifugal work. The

DATA ON TEMPERATURE OF WASH WATER—COLORADO DISTRICT. Campaign 1917-1918.

Factory	Temp. °C. Wash Water	Quarts Wash Water	Per Cent Moisture Wet Sugar	Per Cent Moisture Dry Sugar (Standard)	Apparent Purity Green Syrup	Apparent Purity High Wash	Bags Granulated 100 Cu. Ft. Fillmass	Apparent Purity White Massecuite
Eaton	33	16	1.38	.032	75.3	85.4	38.8	87.8
Greeley	38	15	1.67	.051	76.1	85.2	38.6	88.8
	64	13	1.52	.049	73.9	84.3	41.9	88.2
Windsor	25	17	1.83	.052	76.2	84.7	37.5	88.0
	50	16	1.25	.050	75.0	82.1	37.6	87.3
Ft. Collins	35	20	1.98	.056	76.3	86.1	32.6	87.1
	58	17	1.66	.058	74.2	83.6	34.8	87.0
Loveland	31	18	2.14	.063	77.1	84.3	28.7	87.4
	60	17	1.88	.070	77.6	83.9	27.6	87.0
Longmont	25	18	2.12	.067	77.2	83.5	34.1	87.2
	60	16	1.64	.051	74.6	81.9	36.3	86.1
Brighton	35	17		.056	78.1	86.5	33.4	88.2
Sterling	39	20	1.85	.043	77.1	88.0	30.9	87.6
	66	15	.87	.036	73.3	83.8	35.8	85.7
Brush	62	16	1.25	.036	73.2	83.1	35.9	85.6
Fort Morgan	24	18.4	2.03	.048	73.1	82.3	36.5	86.8
	58	17.5	2.01	.046	72.8	81.6	35.4	86.3

The above data was compiled from the White Pan Sheets and are averages of the periods during which Wash Water of less than 50° C. was being used and when Wash Water of 50° C. or more was in use. Eaton and Brighton did not use the high temperature wash water and Brush did not use low temperature wash water during the campaign. The other factories used low temperature wash water during the first part of the campaign and high temperature during the latter part, the periods varying in length at the different factories. 4-9-18.

centrifugal should not be stopped for discharge until the moisture in the sugar is sufficiently reduced, or otherwise the granulator station will be overburdened and it may be impossible to secure from that station a granulated sugar which will be dry enough to store.

Various mechanical devices are used for measuring and applying the wash water to the sugar. The most common one consists of a stationary, automatic measuring can to which is attached a hose with a sprinkler nozzle. The water is distributed over the face of the sugar by moving the sprinkler head up and down by hand. At some factories mechanical sugar washing machines have been used and found more or less satisfactory. If in perfect adjustment, they will reduce the labor on the station, use less water and give more uniform washing than the hand sprays. Also they are cleaner and safer than the old arrangement. However, the difficulty of keeping them in order mechanically is such that there is a decided difference of opinion as to whether they should be installed in place of the hand sprayers.

One of the most important points to be watched in centrifugal work is the separation of green and wash syrup. Green syrup consists entirely of the mother liquor, while wash syrup consists of a mixture of the mother liquor and a solution of pure sugar and is therefore of a higher purity. For good sugar end work it is essential to keep the green and wash absolutely separate so that the purity of the syrups entering the pans may be properly controlled. The two factors which govern the completeness of the separation are (1) the time at which the lever operating the separating device is moved, and (2) the construction of the separating device. In general practice the shifter should be thrown over just as the first wash passes through the screens. However, if it is desired to raise the purity of the syrup, the time may be delayed a little. Two types of syrup separating devices are in use, known as single syrup spouts and double syrup spouts. With the first type there is a single spout leading to the gutters under the machines, with a movable deflector at the end of the spout which will throw the syrup into either the green gutter or the wash gutter. With this type there is always some syrup left in the spout after the green has passed through which goes in with the wash syrup, and some wash left after washing which goes with the green, thus preventing a good separation. To overcome this the double spouts were devised. With this system, there are two spouts leading from the machine, one for green and one for wash, with the deflector up near the curb. It is readily seen how this device reduces the mixing.

Until a few years ago it was necessary to remove the sugar from the centrifugals by hand and this operation was a very laborious process, but at the present time all of our white centrifugals are equipped with mechanical dischargers which greatly reduce the labor needed in "cutting down" the sugar. There are two general classes of these dischargers, namely, the hydraulic and the hand operated dischargers. Some superintendents prefer the hydraulic while others prefer the hand operated dischargers, and at the present time some factories are equipped with one type and some with the other. While it is generally conceded that the hydraulic dischargers are faster than the hand operated, the maintenance on them is higher, and any water leaking from their cylinders dissolves a certain amount of sugar in the bottom of the centrifugals. The mechanical discharger works exceedingly well in the hands of skilled operators, but in the hands of unskilled men they tend to tear up screens faster and are more dangerous than was the old hand cutting method.

REMELT CENTRIFUGAL STATION

The general arrangement of the remelt centrifugals is the same as that of the white centrifugals, but due to the fact that a massecuite of lower purity, and therefore higher viscosity is worked, the operation is somewhat different.

For best results on remelt sugar the amount of massecuite in the mixer should be kept as small as possible for the reason that the cooling in the mixer increases the viscosity of the syrup and retards the working. The massecuite may be kept in much better condition in the crystallizer than in the mixer. Putting the massecuite from two crystallizers in the mixer at the same time should be avoided as much as possible, for, unless both crystallizers have crystals of the same size, massecuite of uneven grain will be delivered to the centrifugals and so retard their operations. The agitator in the remelt mixer should be moved only at rare intervals, as stirring remelt massecuite increases the viscosity.

Remelt centrifugals should not be charged while in motion, as the high viscosity of the fillmass prevents its rapid distribution in the basket and the machine will not be loaded evenly. The size of the charge taken depends upon the nature of the material being worked, and should be such as to give the greatest capacity and at the same time yield a good quality of remelt sugar. The machines should not accelerate so rapidly as to pack the first crystals too firmly into the screen or the movement of the syrup will be retarded. Remelt machines do better work if they do not reach

their full speed for two or three minutes after they are started. Electrically driven centrifugals are very suitable for this service.

The length of time which should be allowed for the molasses to spin off varies with the size of the charge and the nature of the material, and can be determined only by trial for any given set of conditions. The nature of the material handled is the most important factor influencing the remelt centrifugal work, and is determined by the quality of the liquor boiled and by the pan and crystallizer work. Uneven grain is the most common cause of slow working massecuite and may be formed either in the pan or in the crystallizers. If the massecuite is cooled to too low a temperature, it will become very sticky.. Remelt massecuite should not be worked at a temperature below 40° C.

Remelt sugar is washed in the same manner as white sugar except that a much smaller quantity of water per machine is used and a longer time allowed for the passage of the water through the sugar. The separation of the syrups from this station is very important where low wash is being taken back into the raw pans. The separating devices used are the same as those used on the white side. The importance of making remelt sugar of as good quality as is consistent with low molasses purity cannot be overestimated, especially in factories short of sugar end equipment, as any addi tional impurities carried back into the process with the raw sugar mean additional boiling in the pans and additional material to be handled in the crystallizers and centrifugals.

The points necessary for good centrifugal work may be summarized as follows:

(1) Keep the screens clean at all times. Steam out and wash the machines at least after every strike.

(2) Watch the gutters frequently to make sure they are open and clean, for, if plugged, a mixture of green and wash syrup may take place.

(3) Make the separation of the syrups and shift the levers at the proper time.

(4) See that the proper quantity of water is used. Check up the temperature of the wash water frequently and also the measuring apparatus, in order to make sure it is delivering the quantity of water specified.

(5) Keep the tips of the dischargers in good condition as this will tend to save the screens.

(6) If working a cold or difficult strike, steam may be used in the curb with advantage.

(7) When loading the machine, have it rotating slowly since this prevents excessive vibration on the machine, gives a more even wall of sugar, and, in the case of the white machines prevents any of the massecuite from running into the white sugar scroll.

(8) Bring the centrifugal to a complete stop before putting the discharger into the sugar.

(9) On the white side no off-color sugar should get into the scrolls. If a machine after washing has any discoloration in it, the apron should be so turned that the sugar when cut down will go to the melter, if the white machines are equipped with two scrolls. If no extra scroll is available, either wash again or dig out. One machine full of off-color sugar may cause the remelting of 100 bags of good sugar.

(10) Keep the white sugar scrolls clean, and, when cleaning, make sure no lumps or off-color sugar get to the elevator.

(11) Prevent all syrup or water leaks into the baskets of the white machines and keep the pan under the goose neck clean.

(12) The sugar in the white machines should be dried as much as possible and yet not be in cakes when cut out. This reduces the work of the granulator station.

GRANULATORS

The wet sugar, after being discharged from the centrifugals, falls into a scroll by which it is conveyed to the wet sugar elevator. This elevator carries it to one of the upper floors of the building and discharges the sugar into the wet sugar box. The wet sugar box is usually a hopper shaped storage bin, with one or more variable speed screw conveyors in the bottom which feed each granulator unit. The hopper shape is used because the feed scrolls can be kept full of sugar as long as there is sugar in the box, without it being necessary to have a man at that point to shovel the sugar into the scrolls. It is important that the feed scrolls to the granulators be kept full of sugar all the time in order that the granulators may receive a uniform quantity of sugar, since in most cases the main condition affecting the operation of the granulators is the quantity of moisture introduced by the sugar in a given time.

An ideal granulator installation is one that will dry the sugar to about .04 per cent moisture without destroying any of the gloss,

and at the same time will deliver sugar at a comparatively low temperature, say 40 to 45° C. The latter feature is especially necessary in connection with conveying systems in the warehouse, for if the sugar is discharged from the granulators too hot, it becomes necessary to pile it on the floor and allow it to cool before it is sent to the stack. If the sugar is not cool enough when it is discharged from the granulators, the double handling makes a conveying system impractical and the work is considerably increased even when the trucking and handling are done by hand.

In general a granulator unit consists of a variable speed screw conveyor feed, one or two revolving shells, a large steam radiator, a fan, and a dust collector. The granulator shell consists of a revolving sheet iron drum mounted with one end slightly higher than the other, with a number of shelves or cleats fastened to the inside, and, in some cases, a long steam drum is supported in the middle, revolving with the shell. On the discharge end of the lower drum is fastened a cylindrical screen which separates the lumps from the dry granulated sugar, and this end of the shell is enclosed by a housing in the front of which is often a series of steam coils. The inlet end of the revolving shell is also enclosed and in the housing about this end is a suction fan which pulls air in through the heat coils and the granulator shell and discharges the moist air into a dust box. The direction of the air within the drum is opposite to the direction of the sugar, or, in other words, the air and sugar run counter current.

The most common type of dust box consists of a vertical sheet iron cylinder containing a series of umbrellas and trays over which thin juice or water is run. As the liquid flows from the top to the bottom of the dust box over the umbrellas and trays, it meets the sugar laden air from the granulators going through in the opposite direction, and removes from this air what sugar dust it may contain. A jet of steam is sometimes used in addition to the liquid. The syrup from the dust box is always run back into the process, thereby saving the sugar that has been carried out of the granulators. Unless these dust boxes are operated properly, there may be a considerable loss of sugar, and it should be the duty of foremen to watch the dust boxes for any sign of sugar loss.

The work on the granulator station can and does affect the quality of the sugar in a number of ways which may be summarized as follows:

First—If the sugar is not sufficiently dry, caking and its attendant expense of rehandling will be the result.

Second—If the sugar is too dry, it has a dull appearance, and a loss of sugar also results due to an excessive amount of dust being formed.

From available information it appears that the temperature of the sugar leaving a granulator is roughly one-half the temperature of the air entering. Since the moisture of wet sugar is on the outside of the sugar crystals, it is obvious that the greater amount of evaporation will be obtained in a given time, the more thoroughly and uniformly the sugar is exposed to the air.

The action of the air is to absorb the moisture from the sugar grains and the amount of drying is dependent on the quantity, the temperature, and the extent of saturation of the air entering the system. The lower the temperature and relative humidity of the air entering the heating coils, the greater will be the drying capacity and heat economy.

The air inside the factory, owing to the escaping vapors, is generally of a high relative humidity and also of a fairly high temperature. The air outside of the factory is generally of a low temperature and of a low relative humidity, and upon being heated up, by passing through the steam coils, has a greater capacity for absorbing moisture than does the air taken from the inside of the factory. For this reason it is generally believed that it is advantageous to take the air from outside rather than that from inside the building.

SUGAR WAREHOUSE

After the sugar has been dried in the granulators, it is generally elevated and discharged either directly into the dry sugar bins, or first over a screen and then into the dry sugar bins. The screen is used when it is desired to separate the sugar into two products of a different degree of fineness, otherwise the sugar is not screened after leaving the granulator but goes directly to the sugar bins. From these bins the sugar flows into the automatic sugar scales, which weigh the correct amount of sugar into each bag. The bags are then taken to the sewing machine and sewed. The automatic scales, if properly taken care of and operated, will give very accurate weights, but require a considerable amount of attention and care. The knife edges and all other operating parts should be kept thoroughly clean. In order to determine how accurately the automatic scales are working, the bags, after having been sacked and sewn, should be frequently weighed on a sensitive platform scale. This should be done several times during each strike even when the weights are running uniform, and, if it is

found that weights from the automatic scales are becoming irregular, the trouble should be corrected at once, and every bag should be check-weighed until the automatic scales are again weighing correctly. For example, if every bag was 4 ounces light, it would mean that a customer receiving a car of 1,000 bags would be 250 pounds short, or, if every bag was 4 ounces heavy, the sugar company would lose 250 pounds of sugar on every 1,000 bags of sugar made. After the sugar is properly sacked, it is necessary, with most of our installations, to put it on the floor for cooling before it is piled, owing to the fact that it comes from the granulators at too high a temperature to allow it to be placed directly in the piles.

Since the piles are in many cases 50 bags high, it is important that every bag should be flat and straight, so that, as the pile settles, all different parts of each layer will settle alike and the bags will not be split. Besides the loss of sugar from broken bags and the cost of labor to resack the sugar, there is the cost of the bags themselves, which may be quite large.

The cars in which sugar is to be shipped should be thoroughly inspected by a competent man, and, if found to be in good condition, should be cleaned, all protruding nails taken out, and the floors covered with straw and paper. In most cases it is also necessary to pad the ends of the cars and the door posts with old filter cloth. After the cars are loaded, the doorways are protected by nailing strips of boards across them to prevent any of the bags of sugar from coming into contact with the doors.

No sugar should be shipped from the warehouses in broken or poorly sewed bags, since, if this is done, a considerable loss of sugar may result before the package reaches the consumer.

CHAPTER NO. X

THE LIME KILN

SECTION A

As large amounts of both lime and carbonic acid gas are required as reagents in beet sugar manufacture, it is necessary to produce them on the premises and in connection with the process.

DESCRIPTION OF EQUIPMENT

A lime kiln installation consists of the following units:

Limestone storage.
Coke storage.
Limestone and coke handling equipment.
Lime kiln.
Gas washer.
Gas pump.

LIMESTONE AND COKE STORAGE

It is customary to accumulate during the intercampaign a sufficient supply of limestone and coke to last the entire campaign. This material should be stored so as to take up the least space, and in a location as near the lime kiln house as circumstances will permit, due regard being paid also to the ease of handling from the storage to the kiln.

LIMESTONE AND COKE HANDLING EQUIPMENT

As a rule a small industrial railway with a few side-dump push cars answers very well for conveying the limestone from the storage to the elevator. The car passes over a scale en route to the elevator, and is then dumped into the elevator bucket. It is very essential that correct weights of limestone be obtained, and that these be recorded in a proper manner, as the operation of the kiln depends first of all upon the proportion of coke to limestone.

The coke is usually brought to the elevator in a wheelbarrow, as the amount of it is not sufficient, nor is it convenient, to handle it in cars. The practice is for a wheelbarrow to contain just enough coke for one car of limestone, the coke being dumped either under or on top of the stone in the elevator bucket, or in some cases at

the same time as the limestone, with the idea of mixing the two more intimately.

A bucket elevator is usually employed for hoisting the charge to the kiln, so arranged that it dumps automatically into the kiln on reaching the chute.

LIME KILN

There are many types of lime kiln, but as the Belgian kiln is the one which is most commonly used in the sugar industry, a description of this will suffice.

The kiln consists of two truncated cones, with the large ends or bases joined together; the lower cone is generally much shorter than the upper one and also has more slope.

The casing is made of heavy sheet metal, riveted in such a manner as to be reasonably air tight, and provided with a number of rows of holes, each having a swinging door, the purpose of which is to permit of inspection of the interior of the kiln during operation, and also, if the occasion demands, to allow the use of poker bars for releasing a bridged condition. The casing is lined with fire brick about fourteen inches thick, and between the fire brick and the casing there is left a space of about two or three inches, which is filled with sand or cinders. The purpose of this is to decrease the radiation and to protect the casing against excessive temperatures.

The kiln is supported on legs in such a manner that the bottom is from four to six feet above the floor. The bottom of the kiln is provided with grate bars so arranged that they may be moved sideways to permit the lime to fall on the floor when it is desired to discharge the kiln.

The top of the kiln consists of a bonnet, in which there is a swinging door, which is reasonably air-tight, and is kept closed except for the short periods when it opens to admit the charges. A chute from the top of the elevator conducts the charge to this door. The charge pipe projects downwards into the center of the kiln for a distance of about six feet, the purpose of this being to concentrate the charge so that it will not scatter over the cross section of the kiln.

Two gas pipes are usually connected to opposite sides of the kiln at a point between the bottom of the charge pipe and the top of the kiln, and these two pipes are then brought together into a single pipe of sufficient capacity.

GAS WASHER

A gas washer is a cylindrical vessel provided with an inlet and an outlet for the gas, and also with water spray lines. The gas is cleansed by passing through these water sprays. Suitable water separators are installed in the gas line leaving the washer. As the gas washer is under a slight vacuum, due to the action of the gas pump, the water is discharged by running out under a barometric seal, similar to the method used with a vacuum condenser.

GAS PUMP

As a general rule, the gas pump is of the reciprocating, steam driven, duplex type. This permits of variation in the speed to suit changed conditions, which is not possible with a pump driven by a belt or a motor. The gas pump is the controlling factor in handling the lime kiln, as a certain amount of gas must be removed for each ton of lime burned, and only as much lime will be produced as corresponds to a certain amount of gas.

If the top of the kiln were left open, there would be a natural draft sufficient to burn some lime, although not as much lime as would be burned with the aid of a gas pump. As the gas must be recovered for manufacturing purposes, and must be of a high degree of purity, every effort is made to prevent the leakage of air into any part of the system between the kiln and the gas pump, the whole being under a slight vacuum.

The gas pump draws air into the bottom of the kiln. This air supplies the oxygen for the combustion of the fuel, and the heat of combustion drives off an additional amount of gas from the limestone, so that the gas handled by the pump consists of the oxygen in the air which is drawn into the bottom of the kiln, the carbon dioxide gas produced by the combustion of the coke, and the carbon dioxide gas produced by the decomposition of the limestone, together with such excess air as may have been drawn into the system. The gas pump draws all of this gas from the top of the kiln, compresses it, and forces it under pressure into the distributing system of the carbonation apparatus.

OPERATION

In the operation of a lime kiln, the first requisite is a supply of both limestone and coke of high quality. The limestone must be as free as possible from impurities, of which silica is the most objectionable, and should contain at least 97 per cent calcium carbonate. The coke should preferably contain at least 90 per cent

fixed carbon and should be free from any excessive amounts of sulphur or volatile matter.

It is best to have the limestone broken in as nearly as possible uniform pieces, of four to eight inches diameter. The coke should also be broken into uniform pieces of such a diameter that it will all be consumed; this is best determined by actual experiment.

The limestone and coke should be mixed intimately, and charged into the kiln in such a manner that they will stay mixed. This, however, is more easily said than done, as there is a tendency for the coke and limestone to separate, and also for the larger and smaller pieces of the coke and limestone to segregate, simply as a result of passing through the chute and charging pipe and falling into the kiln. The tendency is for the heavier material, such as the limestone, and in particular the larger pieces of the limestone, to roll farthest; thus there results an accumulation of the finer pieces of limestone and coke in the center of the kiln, and of the larger pieces at the circumference.

It is possible to overcome the effects of this to a great extent by drawing the lime alternately from each side of the kiln, and by changing the point at which the draw is started. The conical shape of the kiln is also of benefit, because, when the level is lowered to a point of greater cross section, the tendency is for the larger pieces to be brought back towards the center of the kiln

In order to get the best results from the lime kiln, a definite policy of uniform operation must be followed, whatever that policy may be. No more lime should be drawn than corresponds to the amount of limestone charged. This is roughly 50 per cent by weight. The kiln should always be kept full. When drawing is started, charging should be started, and both should be carried on at the same time. This avoids allowing the charge of limestone and coke to fall any greater distance than is necessary, and reduces the segregation caused in this manner.

The charging and drawing should be done at regular intervals, starting always at the same hour and taking the same length of time, which should be the shortest possible to accomplish the operation. These intervals should be as short as is consistent with circumstances, not less than two hours, and not more than three hours apart. After all concerned have become accustomed to this regular routine, it will be possible to detect any irregularity in the condition of the kiln by comparing the prevailing condition with a well known uniform condition, which comparison would be impos-

sible if the method of operation were so irregular that no one knew exactly what had been done, or how any particular condition had been produced.

It is a very good plan to have a blackboard hung in a place convenient to the scales, so that an accurate record may be kept of the total weight of limestone charged to the kiln. This record should show the number of skips for each charge, and also the number of wheelbarrows of lime from each draw, and the total. By following a regular system of this kind, it will soon be found that all concerned will become familiar with the characteristic condition of the kiln corresponding to certain operations. The movement of the fire zone up and down with the draw will be apparent, and will be proportional to the amount of limestone charged each time.

The use of a suitable recording thermometer, the bulb of which is installed in such a way as to show the temperature of the gas just as it leaves the kiln, will be found to furnish a record which is invaluable.

Ordinarily the hottest part of the fire where the lime is burned should be about midway of the kiln, and this will not move more than from two to four feet either way with regular operation. This will leave about one-third of the material in the kiln above the fire, where it serves to absorb a portion of the heat, and the bottom third of the kiln will be occupied by burned lime, ranging in temperature from red hot to completely cold.

If short and frequent draws are made, it is a simple matter to be able always to draw cold lime from the kiln, and to follow the rule not to draw any more than has actually cooled down. If hot lime is drawn, it is a sure sign of wrong conditions in the kiln, and this in turn tends to make things worse.

The air which is drawn in for combustion must pass through the body of burned lime, from which it removes the heat, thus cooling the lime, and at the same time effecting an economy of fuel by heating the air for combustion. It is impossible to increase the production of lime by any other course of action than that of pumping more gas, that is by supplying more air to burn additional fuel. All that is necessary is to speed up the gas pump, and to draw more lime at the time each draw is made, in proportion as the speed of the pump has been increased.

The presence of fine pieces of limestone and coke is detrimental because it reduces the air passages and increases the resistance against which the pump has to work, thus reducing capacity. The ideal condition would be to have all pieces of limestone the same

size and all pieces of coke also the same size, and, while this is probably impossible in practice, this knowledge serves as a guide in approaching this condition as closely as possible. Fine coke is especially to be avoided, as this tends to accumulate in the center of the kiln and stops up the air spaces. As a result the air passes through at some other point, and the fine coke is not completely burned. It is much better to throw it away, and it is false economy to attempt to use it when it does more harm than would correspond to the saving.

It is sometimes the practice to inspect the peek holes and thereby pronounce judgement on the condition of the kiln, saying the fire is too high or too low, etc. This is a bad practice, as it is impossible for any one to say just how high the fire should be unless he is familiar with what has been done previously, that is with the history of operation of the kiln for a considerable period.

If, however, the fire by some chance is allowed to get too high in the kiln, so that the temperature of the gas becomes much higher than normal, this may be corrected by gradually lengthening the draw, and by increasing the amount of each draw until the fire has reached the proper position. On the other hand, if by chance the fire is too low in the kiln, this may be corrected by shortening the draw, or by skipping a draw, so as to allow the fire to burn upwards at a greater rate than the lime is drawn.

If the fire is uneven, this may generally be traced to separation of the limestone and coke, or to the presence of either fine coke or fine limestone, or both. The remedy is obvious. In case both unburned stone and well burned lime are drawn out at the same time, this may come from the same cause.

It is impossible, however, to tell just what is the matter with the kiln unless it is properly handled and the zones are maintained fairly distinct. For convenience the kiln is divided into three zones. The upper part is the heat zone in which the coke has not yet caught fire, and in which the gases of combustion pass through the body of the stone and coke, and a portion of the heat is thereby absorbed by them. The combustion zone is the portion between which the coke takes fire and all the coke, or at any rate the greater portion of it, is completely burned. The cooling zone is at the bottom of the kiln, commencing at the point at which combustion is complete. It should contain completely burned lime, ranging from a good red heat down to a completely cold condition.

To correct poor or uneven distribution in the kiln, it is possible at times to draw the lime in a peculiar manner to counteract

this tendency. If the kiln is much hotter on one side than on the other, it helps to equalize conditions to draw a greater amount of lime from the cooler side.

The presence of oxygen in the kiln gas is an indication of air leakage at some point between the combustion zone and the gas pump, and the amount of air which has leaked in may be found by multiplying the percentage of oxygen by five. Thus, the presence of 3 per cent of oxygen would correspond to 15 per cent air leakage, which may be considered excessive. The effect of air leakage is to reduce the capacity of the kiln as regards the gas pump, since the air uses up gas pump capacity which could otherwise be utilized to pump gas and produce lime. The same result will obtain if the gas is not well cooled by the time it reaches the pump, as gas expands in direct proportion to its temperature, and a given weight of gas will therefore utilize correspondingly more capacity of the gas pump at a high temperature than at a low one. To give some idea of the amount of gas which a pump has to handle, 100 tons of limestone of 96 per cent calcium carbonate, burned with 9 per cent of coke of 90 per cent carbon, with the gas cooled to 30° C., and a vacuum of one inch at the pipe suction, will produce 4,659,600 cubic feet of gas, or, if this amount of material is handled in 24 hours, this will amount to 3,235 cubic feet of gas per minute. In the above it is assumed that there will be 33 per cent CO_2 in the gas. If the percentage of CO_2 is lower, the amount of gas will be correspondingly greater.

If for any reason it is necessary to slow down a lime kiln, all that need be done is to reduce the speed of the pump as much as is required, and to draw less lime in proportion to the reduced speed.

In case of a break down of the gas pump, the kiln may be kept in operation by opening the top so as to permit of natural draft, and by drawing lime only in proportion to the travel of the fire upwards. It is a very difficult matter to put out the fire in a lime kiln.

METHOD OF STARTING UP A LIME KILN

It is customary to fire up the kilns about four days before the slicing of beets begins. The usual method of starting a lime kiln is as follows:

The bottom is filled to a depth of about six feet with kindling wood, which is supported by a layer of coarse limestone, over the rails, to keep them from getting too hot. On top of the kindling there is placed a layer of about 2,000 to 3,000 pounds of coke, and

above this about ten tons of limestone, mixed with 15 per cent coke. The kiln is then filled about two-thirds full with limestone, mixed with 10 per cent, or the customary amount, of coke. Care should be taken to fill the kiln first with limestone of uniform size, so as to get an even draft. The kiln is lighted with torches, and allowed to burn with natural draft, or with the booster fan, until the fire reaches the limestone, or until it is necessary to speed up the kilns to produce lime, when the pumps are started and the regular operation of the kiln begins.

SECTION B

The burning of limestone to lime in the Belgian kiln, using inter-mixed coke as a fuel, follows definite and quite simple chemical reactions. Knowing these reactions, the formula weights of the various compounds involved, the relative weights of the gaseous products, and the weights of one or both of the raw materials, it is possible to calculate the weights and volumes of the products. In order to make the calculations readily understandable, we shall for the time being ignore the influence of any impurities which may be present in the limestone or coke, and assume that we are dealing with pure calcium carbonate on the one hand, and pure carbon on the other.

There are two basic and a number of minor reactions involved in the burning of lime, the basic ones being, the thermal decomposition of calcium carbonate into calcium oxide, or quick lime, and carbon dioxide gas; the second reaction is that of the burning of carbon in oxygen diluted with the nitrogen of the air.

The minor reactions include, the decomposition of a portion of the carbon dioxide in the presence of incandescent carbon into two parts or volumes of carbon monoxide; the reactions of producing calcium silicates, ferrates and aluminates from the impurities originating in the limestone, the coke, and the refractory lining of the kiln; the formation of sulphurous and sulphuric acid from the sulphur of the coke, or from calcium sulphate, which is sometimes present in limestone.

Every element or compound has a certain chemical weight, or formula weight, which is distinct from the absolute weight. This formula weight is the ratio of the weight of a molecule of the substance to the weight of a molecule of hydrogen, and indicates the relative proportions in which the substances occur in compounds, etc. The following are the principal substances which need to be considered in a preliminary study of the lime kiln, their formulas and formula weights also being given for reference.

Substance	Formula	Formula Weight
Calcium Carbonate	$CaCO_3$	100
Calcium Oxide	CaO	56
Carbon Dioxide	CO_2	44
Carbon	C	12
Oxygen	O	16

The reactions are the following:

Decomposition of $CaCO_3$: $CaCO_3$ plus heat = CaO plus CO_2
100 56 44

Burning of Carbon: C plus $2(O) = CO_2$
12 32 44

Decomposition of CO_2: CO_2 plus $C = 2(CO)$
44 12 2(28)

Knowing that the reactions take place in proportion to the formula weights and having given the absolute weights of calcium carbonate and carbon, we can calculate the absolute weights of calcium oxide and carbon dioxide.

For simplicity and because practically all the chemical values are commonly calculated in the metric system, we shall do so in this case and refer to kilograms and cubic meters instead of pounds and cubic feet. The weight of a cubic meter of each of the principal gases has been carefully determined by scientists as follows:

Gas	Weight of One Cubic Meter in Kilograms
Oxygen	1.4300
Carbon dioxide	1.9663
Nitrogen	1.2552
Carbon monoxide	1.2515
Air (O and N)	1.2939

Since the gas is analyzed by volume with the Orsat or similar apparatus, it is customary to express the composition of the gas by volume, and since any gas expands with an increase of temperature, or a lowering of the absolute pressure, the standard volume is taken as at Zero C. and 760 millimeters pressure, and for any variation from these conditions, due allowance is made.

Making use, then, of the formula weights of the various substances, the weights of a cubic meter of the respective gases, and knowing the weight of a product or a raw material, a series of factors may be derived covering the whole field of lime burning, which may be used in calculating the unknowns for any combination.

TABLE OF FACTORS FOR LIME KILN CALCULATIONS

1. Weight of calcium carbonate $\times$ 0.44 = Weight of CO_2 from same.
2. Weight of calcium carbonate $\times$ 0.56 = Weight of CaO from same.
3. Volume of CO_2 from $CaCO_3$ = 0.44/1.9663 or .22377 cubic meter per kilogram.
4. Weight of calcium carbonate in kilograms $\times$ 0.22377 = Volume of CO_2 in cubic meters.
5. Weight of carbon in coke $\times$ 44/12 or 3.6667 = Weight of CO_2 from coke.
6. 3.6667/1.9663 = 1.8647 cubic meters of CO_2 from one kilogram of carbon.
7. 1 kilogram of carbon therefore results in 1.8647 cubic meters of CO_2.
8. Weight of nitrogen accompanying the oxygen used for combustion of the carbon in the coke is 32/12 $\times$ 77/23 $\times$ weight of carbon = 8.928 $\times$ weight of carbon.
9. Volume of nitrogen equivalent to unit weight of carbon is 8.928/1.2552 = 7.118 cubic meters of nitrogen for each kilogram of carbon.
10. Then—
    - .22377 $\times$ Kilograms of $CaCO_3$ = Cubic meters of CO_2.
    - 1.8647 $\times$ Kilograms of carbon = Cubic meters of CO_2 from coke.
    - 7.118 $\times$ Kilograms of carbon = Cubic meters of Nitrogen.
11. Cubic meters of CO_2 from calcium carbonate and from carbon plus cubic meters of nitrogen from the air = total volume of gas resulting from the lime kiln reactions, exclusive of excess air.
12. Oxygen is present in the air in the ratio of 21 parts to 79 parts of nitrogen by volume, that is roughly one part of oxygen to four of nitrogen or one of oxygen to five of air. The presence of oxygen in the gas indicates the presence of a corresponding amount of air, over and above the amounts needed for the combustion of carbon. Then by multiplying the percentage of oxygen by 100/21 to be exact, or by 5 for approximate calculations, we may determine the relative volume of air which is mixed with the gases resulting from the reactions of the lime kiln.

13. From this the following ratios, useful in quick calculations, are derived:

One kilogram of $CaCO_3$ produces 0.56 kilogram of CaO.

One kilogram of CaO is produced from 1.785 kilograms of $CaCO_3$.

One kilogram of $CaCO_3$ produces .22377 cubic meter of CO_2.

One kilogram of CaO produced, results in .39953 cubic meter of CO_2.

One kilogram of carbon produces 1.8647 cubic meters of CO_2.

One kilogram of carbon burned in air produces 7.118 cubic meters of nitrogen.

One kilogram of carbon burned in air produces 8.9775 cubic meters of gas.

To demonstrate how these factors may be used in practical work, let us assume that we wish to use limestone of 96 per cent $CaCO_3$ and coke of 90 per cent carbon, and that 10 per cent by weight of coke on limestone has been found necessary by experiment to burn the limestone, what would be the analysis of the gas from the reactions, and what would be the volume of the gas from 100 kilograms of limestone?

$100 \times .96 \times .22377 = 21.4819$ Cubic meters of CO_2 from limestone

$100 \times .10 \times .90 \times 1.8647 = 16.7823$ Cubic meters of CO_2 from coke

$100 \times .10 \times .90 \times 7.118 = 64.0152$ Cubic meters of nitrogen from air used for combustion

Total Gas ..... = 102.2794 Cubic meters

Subtract nitrogen ..... = 64.0152 Cubic meters

Difference ..... = 38.2642 Cubic meters of CO_2

$38.2642/102.2794 \times 100 = 37.6\%$ CO_2 in total gas.

$21.4819/102.2794 \times 100 = 21.0\%$ CO_2 from $CaCO_3$.

$37.4 - 21.0 = 16.4\%$ CO_2 from coke.

$16.4/37.4 \times 100 = 43.8$, the percentage of the CO_2 in the gas which came from the combustion of the carbon of the coke.

$100 - 43.8 = 56.2\%$, the percentage of the CO_2 in the gas which came from the decomposition of the limestone.

For this illustration we have taken a condition which is probably impossible to obtain in practice, as there is always excess air present in the gas as shown by the oxygen content.

The analysis by volume of the above gas would be:

Carbon dioxide	37.4
Carbon monoxide	none
Oxygen	none
Nitrogen (by difference)	62.6
Total	100.0%

Suppose we burn limestone under the conditions above given and find that the analysis of the gas actually is:

Carbon dioxide	35.6
Oxygen	1.0
Carbon monoxide	none
Nitrogen	63.4
Total	100.0%

What has taken place is that some air has become mixed with the gas produced by the decomposition of the limestone and the combustion of the carbon. This is shown by the presence of the 1.0 per cent of oxygen which indicates 5 per cent of air. In this mixture then we have 95 per cent of gas from the kiln reactions and 5 per cent of air. To determine the percentages of the original gas, we have only to divide the percentage of CO_2 found by analysis by 95×100, thus: $35.6/95 \times 100 = 37.4$, the difference between this figure and 100 is the percentage of nitrogen in the original gas.

If we should assume that we used only 8 per cent of coke or $.90 \times 8 = 7.2$ per cent of carbon, we would find that the percentage of CO_2 in the gas would be higher than in the first example given where 10 per cent of coke was used, while, should we assume a third case in which 12.0 per cent of coke would be used, or 10.8 per cent of carbon on limestone, the percentage of CO_2 in the gas would be less than in the first example.

To make this clearer, suppose we should take a quantity of calcium carbonate and place it in a closed retort with an outlet to a gas holder, so that there would be no mixture of air with the gas evolved, and heat the retort to the dissociation temperature of calcium carbonate, the gas upon analysis would show 100 per cent CO_2.

In practice we have the limestone and the fuel mixed together so that the gases evolved are a mixture of the 100 per cent CO_2 from the calcium carbonate, and the dilute combustion gas from the coke which can never contain more than 21 per cent of CO_2, so that the greater the percentage of carbon on limestone in the coke, the greater will be the amount of nitrogen drawn in as a constituent of the air used for combustion, and the lower will be the percentage of CO_2 in the total gases, while the less the percentage of carbon, the higher will be the percentage of CO_2 in the gases.

As the purity of CO_2 from both the $CaCO_3$ and the carbon is always constant, and the only variable will be the proportion of carbon to limestone, it is quite easy to calculate a table or set of curves, from which the amount of gas produced may be calculated for any proportion of coke to limestone. Plate No. 22 has been calculated for this purpose, taking as a basis the amount of CO_2 which will be produced by the burning of 100 parts (or tons) of 100 per cent pure $CaCO_3$, with 10 per cent of pure carbon on the calcium carbonate. If the limestone used has less than 100 per cent $CaCO_3$, there will be proportionately less CO_2 from $CaCO_3$, and the amount of CO_2 from carbon will vary either way as the proportion of carbon to limestone varies, so that, if in any case we have given the percentage of $CaCO_3$ in the limestone, and the percentage of carbon (in coke) on the limestone, there can be determined by the use of the chart just what amount of CO_2 from any such combination would result, as a percentage of the amount of CO_2 which would be evolved from the 100 per cent $CaCO_3$ and the 10 per cent carbon.

The absolute amount of CO_2 from 100 tons of 100 per cent $CaCO_3$, burned with 10 per cent carbon on limestone, is 37,216.869 cubic meters at 0° C. and 760 millimeters pressure.

If the limestone contains 96 per cent $CaCO_3$, and 10 per cent coke containing 90 per cent carbon is used, by the use of the table we find the value 93.3, which multiplied by 37,216.869 cubic meters will give the volume of CO_2 from 100 tons of such limestone. If we wish to have the amount of CO_2 from any number of tons of such limestone burned with such carbon per cent, it is only necessary to multiply 37,216.869 $\times$ 93.3 by the number of tons of limestone, and divide by 100.

The total volume of gas may be derived from the weight of limestone and the gas analysis as follows: If the analysis of the gas shows 33 per cent CO_2, the volume of the total gas will be the

volume of CO_2 thus found, multiplied by 100/33. This is useful in determining the size of gas pump which will be required to burn any quantity of limestone under any given conditions. It will in this case be found necessary to take into consideration also the temperature and pressure of the gas at the pump.

The volume of a gas increases in proportion to the absolute zero which is 273° Centigrade below the freezing point of water, thus if the temperature of the gas at the pump is 50° C., its absolute temperature is 273 plus 50 = 323°, and the increase in volume is as 323/273 = 1.183. Multiplying the calculated volume at zero by this factor gives the volume at 50° C.

A reduction of the pressure below 760 millimeters also causes an increase in the absolute volume, which increase is inversely proportional to the absolute pressure. Thus if the observed pressure should be 630 mm of mercury, the increase in volume would be as 760/630 = 1.206. Multiplying the volume last above found by this factor gives the actual volume of gas under the observed conditions.

To facilitate making these calculations, tables have been calculated, showing the factors for temperatures between zero and 100° and pressures from 560 to 630 mm of mercury, also the corresponding inches of water. These tables will probably cover any ordinary conditions.

TABLE OF FACTORS FOR TEMPERATURE CORRECTION

Multiply the calculated volume of gas at 0° C. and 760 mm by factor.

Temperature (° C.)	Factor	Temperature (° C.)	Factor
5	1.018	55	1.202
10	1.036	60	1.220
15	1.055	65	1.238
20	1.073	70	1.256
25	1.091	75	1.274
30	1.110	80	1.292
35	1.128	85	1.310
40	1.146	90	1.329
45	1.164	95	1.347
50	1.183	100	1.366

Plate No. 22.

CHART FOR CALCULATING VOLUME OF GAS FROM LIME KILN.

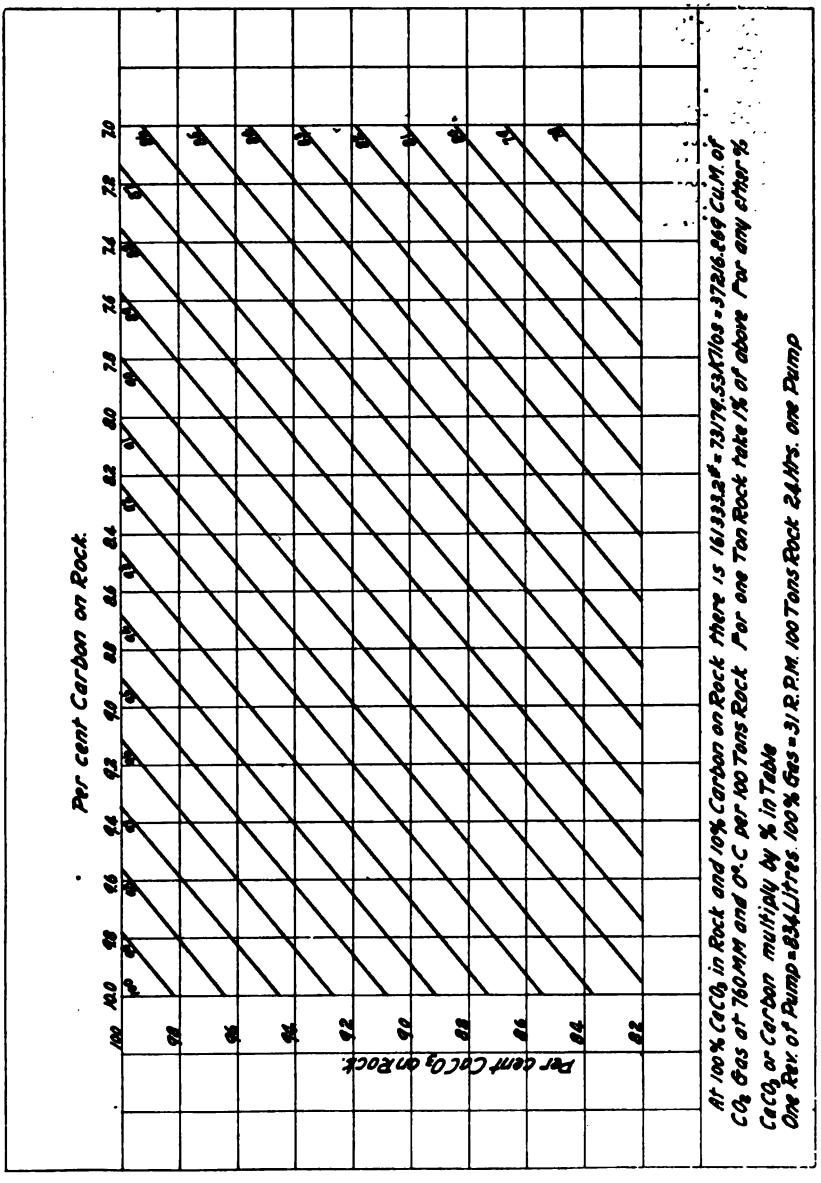
Per cent Carbon on Rock.
Per cent $CaCO_3$ on Rock.
At 100% $CaCO_3$ in Rock and 10% Carbon on Rock there is 1613332 ft. = 73179.534 Mts = 37216.669 Cu.M. of CO_2 Gas at 760 MM and 0° C per 100 Tons Rock. For one Ton Rock take 1% of above. For any other % $CaCO_3$ or Carbon multiply by % in Table
One Rev. of Pump = 834 Litres. 100% Gas = 31 R.P.M. 100 Tons Rock 24 Hrs. one Pump

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TABLE OF FACTORS FOR PRESSURE CORRECTION

Multiply the calculated volume of the gas by the factor.

Absolute Pressure MM Mercury	Factor	Absolute Pressure MM Mercury	Factor
630	1.206	595	1.276
625	1.216	590	1.290
620	1.226	585	1.300
615	1.236	580	1.312
610	1.246	575	1.323
605	1.256	570	1.335
600	1.266	565	1.343

As pressures are generally observed in inches of water, it is useful to have a table for inches of water corresponding to millimeters of mercury. To use this table, observe the inches of water and find the millimeters of mercury closest to the observed inches of water.

TABLE SHOWING INCHES OF WATER EQUIVALENT TO MILLIMETERS OF MERCURY

Inches of Water (Vacuum)	Absolute Pressure Millimeters of Mercury	Inches of Water (Vacuum)	Absolute Pressure Millimeters of Mercury
1.0	628.2	16.0	600.3
2.0	626.3	17.0	598.6
3.0	624.5	18.0	596.6
4.0	622.6	19.0	594.6
5.0	620.7	20.0	592.6
6.0	618.9	21.0	591.2
7.0	617.0	22.0	589.2
8.0	615.1	23.0	587.4
9.0	613.3	24.0	585.5
10.0	611.1	25.0	583.6
11.0	609.6	26.0	581.6
12.0	607.8	27.0	580.0
13.0	605.9	28.0	578.0
14.0	604.0	29.0	576.2
15.0	602.0	30.0	574.6

Plate No. 23 has been calculated by the use of some of the factors above given, to supply a ready method of determining the percentage of CO_2 in the gas from any given combination of percentage of $CaCO_3$ in the limestone and percentage of carbon on limestone. In order to use this chart, it is first necessary to deter-

mine the percentage of CO_2 in the original pure gas, by calculating the proportion of air admixture as previously illustrated.

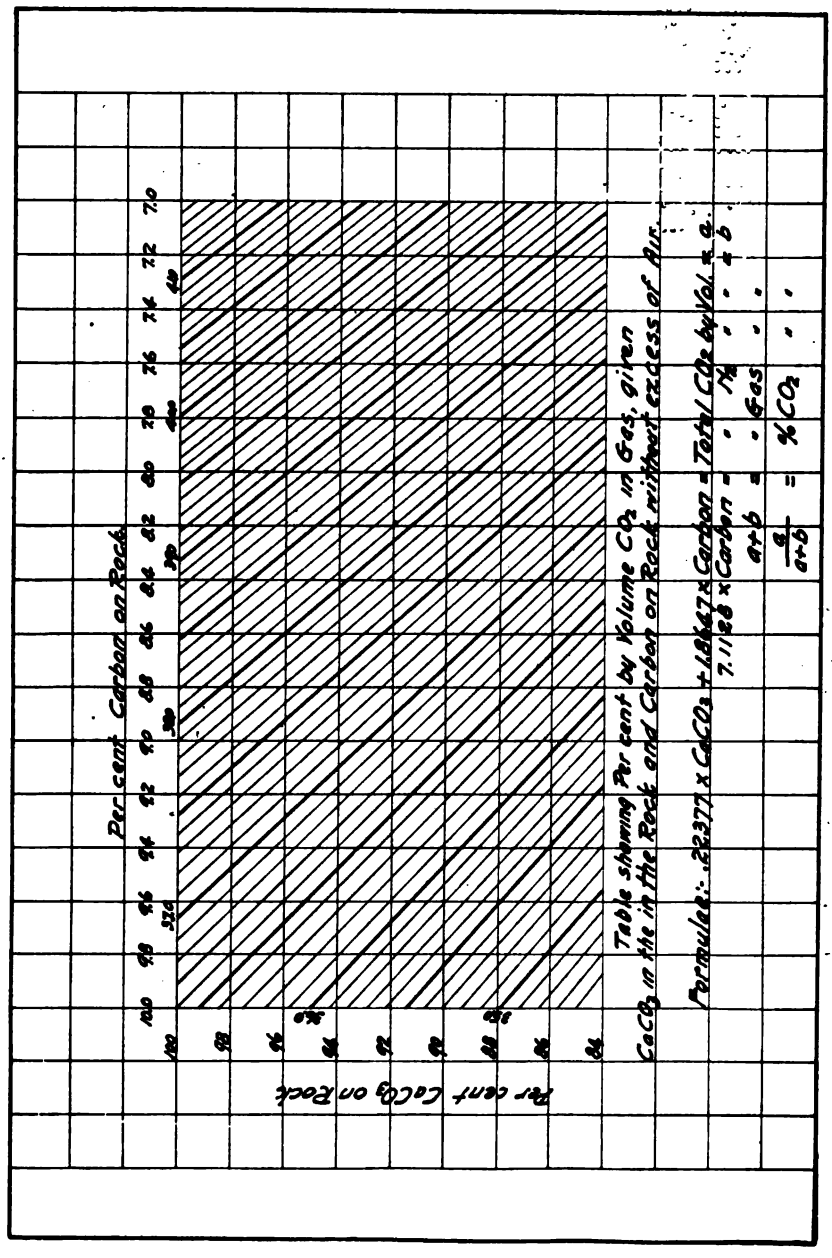
This chart can be used in a number of ways. Knowing the percentage of $CaCO_3$ in the limestone, the percentage of carbon in the coke, and the percentage of coke used, it can be used to show whether or not combustion and decomposition are complete in the kiln. For example, if we have 98 per cent of $CaCO_3$ in the limestone, and are using 10 per cent of coke containing 90 per cent of carbon, the percentage of CO_2 in the gas as shown by the chart should be 37.4.

Knowing that the limestone is completely burned and that the coke is all consumed, to determine the relative amount of each which is being used, we have only to analyze the gas and consult the table. If the quantities thus found do not correspond quite closely to the weights shown in the reports, we know that there is some error, either in the weights of the coke and limestone, or in the analyses used. It very frequently happens that gas anaylses as recorded upon the laboratory records, upon being subjected to this examination, indicate impossible conditions, due to improper taking of the sample or careless performance of the analyses, but such results are generally so far from correct as to be apparent upon first inspection.

It is apparent that the gas pump is the controlling factor in the production of lime, because a definite quantity of gas must be pumped for each ton of lime produced, and therefore the lime can be produced only as the gas in removed. Leaving for later discussion the influence of the size of the lime kiln upon capacity, let us see what can be learned by a few calculations regarding the gas pump.

On Plate No. 22 and the notations at the bottom of same, it is shown that in order to pump the quantity of pure CO_2 gas produced when 100 tons of limestone, of 100 per cent $CaCO_3$, are burned with 10 per cent of carbon on limestone, it will require 31 revolutions per minute of a duplex gas pump as used at Loveland, with cylinders 18 inch by 30 inch, but since the gas as actually pumped contains so much nitrogen and air, that it has only, say 33 per cent CO_2, and since moreover it has a temperature of 50° C., and the pressure at the pump suction is 10 inch water vacuum, the actual volume to be pumped is greater. Further, instead of 100 per cent of $CaCO_3$ in the limestone, we have only 96 per cent and the carbon is 9 per cent on limestone instead of 10 per cent, as assumed in the Chart, and instead of 100 tons of limestone to be burned we may have any number of tons.

Plate No. 23.


Per cent CaCO3 on Rock
100
98
96
94
92
90
88
86
84
Per cent Carbon on Rock
1.20
1.28
1.36
1.44
1.52
1.60
1.68
1.76
1.84
1.92
2.00
2.08
2.16
2.24
2.32
2.40
2.48
2.56
2.64
2.72
2.80
Table showing Per cent by Volume CO2 in Gas, given
CaCO3 in the Rock and Carbon on Rock without excess of Air.
Formulae: .22377 x CaCO3 + .16867 x Carbon = Total CO2 by Vol. = a.
7.1128 x Carbon = " N " = b.
a+b = " Gas " "
a/a+b = % CO2 " "

CATALOGUE
LIBRARY OF

Three formulas can be derived, from the information which we now have, to calculate any of these values.

Let the tons of limestone to be burned be designated by.....R
The proportion of gas by Plate 22 by.....P
The volume of gas at observed temperature by.....T
The volume of gas at observed pressure by.....V
The per cent CO_2 by analysis in the gas by.....G
The R. P. M. of the pump (Loveland) by.....M

Then—

$$M = \frac{31 \times R \times PTV}{G} \text{ and } R = \frac{M \times G}{31 \times PTV} \text{ and } G = \frac{31 \times R \times PTV}{M}$$

By applying one or all of the above three formulas to actual performance of a lime kiln installation, many valuable lessons may be learned, and generally it is found that things are not what they are supposed to be.

As the capacity of the gas pump at Loveland is .834 cubic meters per revolution, to apply these formulas to any other size of gas pump it is only necessary to multiply the value (31) in the chart by a factor representing that which the capacity of the pump in question bears to .834 cubic meters, or better to make a recalculation of Plate 22 to fit the case, which will result in a value other than 31, as in the Loveland example, and which value is to be substituted for it in the chart and formulas.

It is clear that the less the volume of gas from a unit quantity of limestone, the less pump capacity is required. This knowledge is of great value in modern beet sugar plants where the slicing capacity has been greatly increased until it is necessary to crowd the lime kilns to the utmost to produce the amount of lime required.

Thus we have seen, that the volume of gas per ton of lime is increased by an increase in the percentage of carbon in the coke, by higher vacuum as pumped, by higher temperatures as pumped, and by leakage of air into the gas, so that all these points should be looked to if one desires capacity, it being generally the case, that the gas pumps are operated at the highest allowable speed, with no auxiliary available. The savings to be made by reducing the amount of coke will be gone into later. The remedies for the other conditions mentioned are so obvious as to be easily discovered upon inspection.

So far, only the chemical reactions, and calculations of the quantities of the materials and products, have been discussed.

These reactions and calculations will be found a very useful guide to the development of operating practice, and a better understanding of the whole problem of burning lime. For these reasons they should be mastered before taking up the discussion of the practical operation of lime kilns which follows.

As far as operating practice is concerned, a lime kiln may be compared to a furnace, as the factors influencing the one apply to the other, with some modifications. The heat consumption of a lime kiln is made up of the following components:

1. That required to raise the temperature of the rock to that of the dissociation temperature.
2. That required for the dissociation of the calcium carbonate.
3. That required to make good the losses.

The amount of heat required for 1 may be calculated from the temperature and the specific heat of limestone. The amount of heat required for 2 may be taken as 425 calories per kilogram. The losses are determined by difference.

The heat losses may be separated into the following divisions:

1. The heat required to raise the temperature of the total lime kiln gas from the temperature of the entering air, to the temperature of the gas on leaving the kiln.
2. The heat required to raise the temperature of the lime as drawn from the kiln, above the temperature of the limestone entering.
3. The radiation losses.

To calculate a heat balance and segregate the losses so that their relative importance can be realized, the Calories in the coke are debited, then credited with the various items of heat required, the losses are calculated and credited, and the difference between this total and the amount credited is the radiation loss.

A typical result of such a calculation, which is described in detail at the end of this lecture, is as follows:

Total coke introduced = 9.0% on limestone = 100%.		
To supply 1 and 2	5.970% =	66.4% of the coke used
Loss in gas	1.374% =	15.3% of the coke used
Loss in lime	.337% =	3.7% of the coke used
Loss in excess air	.132% =	1.4% of the coke used
Radiation losses	1.187% =	13.2% of the coke used
Total	9.000% =	100.0% of the coke used

The main opportunity for heat economy in this case is seen to be in reducing the temperature of the exit gas, and in reducing radiation. Another small economy, which is sometimes not insignificant, is that of avoiding a reduction of CO_2 to CO, as this will absorb heat which otherwise would perform useful work.

A lime kiln may be divided into a number of zones which upon close observation will be found to be quite plainly defined.

1. The heating zone includes the upper portion of the kiln down to the point where the fuel starts to burn. It is here that the cold stone is heated by the hot gases passing through, and this results in saving some of the heat in the gas.

2. The burning zone is located in the central portion of the kiln and includes practically the entire portion where the fuel is burning. In this zone the temperature should be somewhat above that of the dissociation of calcium carbonate, but is generally much higher in practice.

3. The cooling zone is the remaining lower portion of the kiln and includes only the area occupied by burned lime, through which the air for combustion of the fuel must pass, serving the double purpose of cooling the lime, and preheating the air.

4. Some authors also speak of an equalizing zone, that portion of the kiln above the limestone and surrounding the charge pipe. This space serves the same purpose as the air chamber on a pump.

In designing a lime kiln, if the capacity required and the time of burning are agreed upon, the size of the zones required to perform the functions assigned to each may be easily calculated. The proportion which each zone bears to the total cubic contents of the kiln will have a marked influence upon the heat economy of the operation as well as upon the actual burning of the limestone, and also upon the gas pump and gas washers.

The time of burning will depend upon several things, viz., the nature of the limestone, the size of the pieces used and the temperature of burning.

Calcium carbonate may be completely dissociated at temperatures as low as 800° C., with a certain size of pieces, and a certain time of exposure, but if the time be shortened or the size of the pieces of limestone be increased, then the temperature must be increased in order to burn an equal amount of lime in the same time. As a rule temperatures around 1300° C. and even higher prevail.

The temperature to which limestone is exposed in burning has another important bearing upon results. As it is practically impossible to obtain limestone free from such impurities as silica, iron and alumina, exposure to high temperatures will result in the chemical combination of some or all of these impurities with calcium oxide, rendering such calcium oxide inactive chemically, and therefore valueless in sugar manufacture. From certain evidence at hand as a result of some investigations on this subject, it is believed that, as a rule, more than 10 per cent of the lime produced in our kilns is thus rendered worthless.

The presence of potash and soda in the limestone and in the ash of the coke, and the presence of these and the other substances, mentioned above, in the refractory lining of the kiln, is also harmful for the same reasons, but the effect is of less importance on account of the relatively smaller amount of impurities from these sources.

For the control of the operation of lime kilns, a good system of simple records should be devised and used faithfully. The amounts of limestone and coke charged, and of lime drawn, should be shown, preferably by a system of tallying on a blackboard, which should be in plain sight.

The installation of a recording thermometer, the bulb of which shall be so placed as to show the temperature of the gas immediately upon leaving the kiln, is very essential to a good control of operation. The shape of the curve and ranges of temperature, as shown by the chart of this thermometer, will, with some little experience, enable the operator to judge, with remarkable accuracy, just what has taken place during any 24 hours of operation, and will also indicate the position and cyclic movements of the burning zone and the relative intensity of the fire in the burning zone.

Further a recording draft gauge placed at the top of the kiln, to show the actual kiln draft, and a similar one at the suction of the pump will be found helpful, and a recording thermometer at the suction of the pump, will be necessary in order to supply data for calculations. As there is a considerable variation in the speed of the ordinary gas pump, a revolution counter should be used to determine the average speed.

It has been mentioned elsewhere that the amount of CO_2 gas from a coke fired kiln is in excess of the amount actually required for carbonation purposes. Theoretically, with a perfect absorption of CO_2 from the gases, the CO_2 from the limestone alone would be sufficient for the purpose. However, as the gas distributors are

more or less crude and the absorption is usually only from 50 to 75 per cent, more than the CO_2 from the limestone is required for carbonation.

While ordinarily, with gas pumps of sufficient capacity, this condition is entirely satisfactory, cases have frequently arisen where there was an object in increasing the absorption efficiency of the gas in the carbonatation, on account of lack of pump capacity, which would then permit the use of a fan to draw off a certain portion of the gas and waste it to the atmosphere. This can be done to the extent that the efficiency of absorption is increased, so that an additional amount of lime in excess of the capacity of the pump can be produced by the aid of the fan.

The function of the gas washer is to remove dust, tar and other impurities from the gas and at the same time cool it to a temperature suitable to the circumstances. This is ordinarily done by subjecting the gas to the action of sprays of water in an apparatus of the general type of a spray condenser, the water from this flowing away through a barometric seal. Often this gas washer is so constructed and used as to require the gas to rise through a considerable column of water, which results in an increased vacuum, and increased volume of the gases to be pumped per ton of lime produced. This is not essential to the washing of the gas, and causes a reduction of kiln capacity which is sometimes not desirable.

As the gas pump is the measure of the lime burning capacity of the kiln, it is essential that the pistons and cylinders should be in perfect mechanical condition, so that each revolution actually measures a definite volume of gas, which multiplied by the revolutions of the pump, and taking into consideration temperature and pressure, is an absolute measure of the volume of gas pumped.

A close attention to these details and the calculation of results by the plans outlined above frequently reveal that the gas is leaking past the pistons to some extent, which introduces an element of uncertainty into the calculations. It has in some instances been found possible to correct this condition by substituting hydraulic cloth packing for the piston rings of the pump, and, if the temperature of the gas is kept as low as it should be, there will be no trouble from the burning out of this piston packing.

It is in some cases found profitable to purchase lime from outside, where the capacity of the kilns is not equal to the requirements. This amount is determined by the amount of CO_2 gas which is available over and above the amount required for carbonatation,

taking into consideration the efficiency or possible increase in absorption efficiency of the gas distributors.

This may be determined by a calculation, an example of which is here given.

Assume the following conditions:

96% $CaCO_3$ in the limestone)
8.0% carbon on rock) From Plate 22 find P = 88.8
Temperature of gas as pumped 30°) T = 1.110
Pressure of gas = 740 mm of mercury) V = 1.246
PTV = 1.228
Pump 90 R. P. M.
Gas 39.0% CO_2

From the above a calculation indicates that the tons of limestone burned should be:

$$R = \frac{M \times G}{31 \times PTV} \text{ or } R = \frac{90 \times 39}{31 \times 1.228} = 92.8 \text{ tons limestone.}$$

for simplicity say 92 tons.

92 × .96 = 88.32 tons $CaCO_3$ from limestone.
88.32 × .44 = 38.86 tons CO_2 from limestone.
92 × .08 = 7.36 tons carbon
7.36 × 3.666 = 26.93 tons CO_2 from carbon
38.86 plus 26.93 = 65.79 total tons CO_2 per 24 hours.
65.79 × .70 = 46.06 tons utilized in carbonation with an absorption efficiency of 70%.
46.06/.44 = 104.7 tons of $CaCO_3$ which it will be possible to precipitate with that amount of gas at 70% absorption efficiency.
104.7/.96 = 109 tons of limestone of 96% $CaCO_3$.
109 — 92 = 17 tons limestone which may be burned by the use of fans, or the equivalent amount of lime which may be purchased from outside, and carbonated with the gas available.

The following calculation of the heat balance of a lime kiln will be found useful as a guide:

1. Heat lost in escaping gasses without excess of air.

For 100 tons of limestone at 96% $CaCO_3$ and 9% of coke at 84% carbon, there will be, according to Plate 22:
86.8 × 37,216.869 cubic meters = 32,304.27 cubic meters, which is equal to 63,535.5 kilograms of CO_2.
Under the above conditions the pure gas will be 40% CO_2 (see Plate 23).

Then: 32,304.27/.40 = 80,760.677 cubic meters of total gas, which will contain 80,760.677 × .60 = 48,456.406 cubic meters of nitrogen.

48,456.405 × 1.2552 = 60,822.48 kilograms nitrogen.

Specific heats used—

CO_2 = 0.217 N = 0.244 CaO = 0.217

The heat lost then will be:

63,535.5 × 0.217 × 295.5 + 60,822.48 × .244 × 295.5 = 8,462,200.995 calories.

Where the temperature of the escaping gas is.....315.5

The temperature of the atmosphere is..... 20

Difference .....295.5° C.

$$\frac{8,462,200.995}{8080} = 1,047.3 \text{ kilograms carbon}$$

= 2,308.87 pounds of carbon

= 1.1544 tons of carbon

= 1.1544/84 or 1.3740 tons coke.

2. Heat lost in hot lime drawn from kiln.

For 100 tons of limestone at 96% $CaCO_3$, the temperature of the lime as drawn being 200° C., and the temperature of the atmosphere being 20° C.,

The products of the burning operation are:

.96 × 44 = 41.36 parts CO_2

96 — 41.36 = 54.64 parts CaO

100 — 96 = 4.0 parts impurities.

54.64 + 4 = 58.64 parts drawn as lime

.5864 × 2000 = 1,172.8 lbs. lime per ton limestone

1,172.8/2.2046 = 531.978 kilograms lime.

The heat lost then will be:

100 × 531.978 × .217 × 180 = 2,077,906.068 calories.

2,077,906.068/8080 = 257.978 kilos of carbon.

257.978 × 2.2046 = 566.67 pounds of carbon.

= .28333 tons of carbon

.28333/.84 = .337 tons of coke.

3. Heat lost in excess air in kiln gas.

All oxygen in gas represents five times that amount of air which has leaked in.

Assume that the gas analysis shows 2% of oxygen = 10% air,

Total cubic meters of gas without excess air is 80,760.677,
80,760.677/.90 = 89,734.985 cubic meters of total gas and air.
Subtracting from this last amount the gas alone = 8,973.408 cubic meters of air.
8,973.408 × 1.294 = 11,611.50 kilograms of air
11,611.59 × 0.237 × 295.5 = 813,200.288 calories
813,200.288/8080 = 100.6436 kilograms of carbon
= 221.899 pounds of carbon
= .1109495 tons of carbon
= .13208 tons of coke.

4. Heat generated from the coke.

Assume 9% coke on limestone, to have 84% carbon = 7.5% carbon on limestone.
.075 × 100 = 7.5 tons carbon per 100 tons limestone.
7.5 × 2000 = 15,000 pounds carbon
15,000/2.2046 = 6,803.955 kilograms carbon
6,803.955 × 8080 = 54,975,956.4 calories.

5. Heat required to dissociate 100 tons of 96% limestone.

Assume 425 calories required to dissociate one kilogram of $CaCO_3$.
2000/2.2046 = 907.194 kilos in a ton
907.194 × 425 = 385,557.45 calories per ton of $CaCO_3$
385,557.45 × 100 = 38,555,745 calories per 100 tons of $CaCO_3$
38,555,745 × .96 = 37,013,515.2 calories per 100 tons of limestone.
37,013,515.2/8080 = 4,580.88 kilograms of carbon.
4,580.88 × 2.2046 = 10,099.008 pounds of carbon
= 5.0199 tons of carbon
= 5.97 tons of coke per 100 tons of stone.

6. Lime kiln heat balance.

Heat values expressed in per cent on limestone, and per cent on coke.

	Per Cent on Limestone	Per Cent on Coke
For dissociation of $CaCO_3$	5.970	66.4
Lost in hot gas	1.374	15.3
Lost in hot lime	.337	3.7
Lost in excess air	.132	1.4
Radiation (by difference)	1.187	13.2
Totals	9.000%	100.0%

By following the above illustration under actually observed conditions, the operator may obtain a good analysis of the situation. In the present case it is seen that the losses in excess air up to 10 per cent are comparatively insignificant, also with pulling lime of 200° C. The principal savings to be made would be in reducing the temperature at which the gases leave the kiln, by having a larger amount of cold limestone for them to pass through, and by using some type of insulation on the kiln.

The foregoing, while by no means a complete exposition of the theoretical side of lime kiln operation, covers, however, all the main points which will be met in the sugar industry.

PROBLEMS

(1) A factory cut 100,000 tons of beets during the campaign. The limestone used per cent on beets was 5.25. The burned lime is 56% on limestone and the coke used was 10.98% on limestone.

What was the tonnage of burned lime produced?

What was the tonnage of coke used?

What was the percentage of coke and burned lime on beets?

If limestone is worth $3.00 per ton and coke $10.00, what would be the saving if the consumption of burned lime was reduced .25% on beets?

Example

A gas analysis shows the following:

CO_2	32.0%
O	3.0%
CO	0.4%

What is the per cent of CO_2 in the undiluted gas?

Let A = % CO_2 in gas.
B = % O in gas.
C = % CO in gas.
D = % CO_2 in undiluted gas.

$$\text{Then } D = \frac{A + .5\,C}{100 - 5\,A} \text{ or } \frac{32.0 + (.5 \times .4)}{100 - (5 \times 3)} = 37.9$$

(2) In the above example if the limestone used contained 96% $CaCO_3$, what was the per cent of coke being used on limestone if the coke was 85% carbon? (See plate 23.)

CHAPTER NO. XI

STEFFEN PROCESS

SECTION A

As stated in the lecture on "Crystallization", the molasses separated from the remelt massecuite is an impure sugar solution in which the non-sugars have accumulated to such an extent that the sugar contained therein cannot be crystallized. The molasses may be sold for cattle food or the sugar in it may be separated from the non-sugars by special processes and refined. Several desugarizing processes have been worked out and used, but, for the conditions under which we operate, the Steffen process has proven the most profitable.

The Steffen process takes advantage of the fact that, under suitable conditions, lime and sugar will unite to form an insoluble compound, composed of three molecules of lime and one molecule of sugar. This compound is known as tri-calcium saccharate. If a sufficient quantity of finely powdered quick lime is added in the cold to a dilute sugar solution, the cold insoluble saccharate will be formed. By this method it is possible to remove by precipitation from 94 to 95 per cent of the sugar originally in the solution. In usual practice, however, only sufficient lime is added to precipitate about 90 per cent of the sugar in this way, and the larger portion of the remainder is removed by the hot saccharate process, in which the filtrate from the cold process is heated to about 85° C., causing the precipitation of the hot tri-calcium saccharate.

The molasses from the main house, generally of about 80° to 85° Brix, is pumped to the Steffen house, where it is diluted in the "Cooler Solution Tank" to a solution containing from 5 to 7 per cent sugar. This tank is usually cylindrical and is equipped with stirring arms which rotate at a speed ranging from 9 to 21 R. P. M. A definite quantity of molasses is weighed into this tank, a sufficient quantity of water to reduce the concentration of the solution to the desired point is added and the whole is thoroughly mixed by the stirring arms. These cooler solution tanks vary in size at the different factories from those sufficiently large to hold enough solution for one cooler (usually about 200 cubic feet) to those large enough to hold the solution for four coolers. After the molasses has been properly diluted in the solution tank, a definite volume of the solution is drawn into the cooler, the agitator and the lime

adding device are started, and the separation of the sugar and non-sugars begins.

After all of the lime has been added, the "Finished Cooler Solution" is pumped from the coolers to the cold saccharate filters, where the insoluble saccharate is retained, while the waste water containing the greater part of the impurities is sent to the sewer or potash reservoir, or, if the hot saccharate process is in operation, to the hot saccharate heating tanks. The cake retained in the filters is then thoroughly washed, the wash water being used to dilute the molasses for the next cooler solution, and the saccharate cake, after being removed from the presses, is mixed with a certain amount of sweet water and returned to the main house, where it is added to the first carbonation. The lime contained in this saccharate cake defecates the raw juice, while the sugar, after the lime has been removed by carbonation, becomes an integral part of the beet juice, goes on through the regular process, and the greater part of it is finally recovered as granulated sugar.

The cooler generally in use consists of a vertical cylindrical shell, or body, with two tube sheets into which cooling tubes of 2½-inch diameter are rolled. In the center of the apparatus is a large circulating well containing a propeller, which keeps the solution in rather violent agitation by forcing it down through the well and up through the cooling tubes. The cooler solution is contained on the inside of the tubes and well, while the outside of the tubes is surrounded by cooling water. The lime must be in the form of a very fine powder and is added gradually by means of a scroll with or without a bolter. The circulation of the solution in the cooler is of the greatest importance, for it requires rapid movement in order to bring the lime and solution into the most intimate contact, and also this rapid movement allows the cooling water to keep the temperature of the solution at a minimum. Since the charge of molasses for each cooler is weighed, the quantity of sugar in it is known, and a weighed amount of lime powder is added which precipitates the greater part of the sugar as tri-calcium saccharate.

In the practical operation of the coolers the following points should be carefully watched:

(1) The weights of molasses must be accurate, and care must be taken that all the molasses drains into the solution tank after each weighing, since cooler solutions of uneven sugar content, and consequently waste water of uneven sugar content, will result if this point is not watched.

(2) The lime must be accurately weighed to each cooler, and care taken that all the lime weighed out is delivered to the cooler.

(3) The coolers must be completely emptied before a new solution is drawn in.

(4) The cooling water must circulate properly at all times.

(5) The cooler should be inspected every day and any plugged tubes opened up.

(6) There is a definite height to which coolers should be filled, and this height should be rigidly adhered to.

(7) If it is necessary to hold a cooler after all the lime has been added, the propeller should be kept running until the cooler is dropped.

Attention to details and carefulness in the operation of this station will add much to the efficiency of the Steffen House. Care in keeping the cooler solution of even sugar content and adding the lime evenly will reduce the sugar loss in the waste water and increase the daily sugar production.

The lime added to the cooler should be in a very finely divided condition, or, in other words, the "Per Cent Grit" or "Per Cent Coarser than 200 mesh" should be as low as possible. The lime, after being drawn from the kiln, if hot, is allowed to cool, and is then fed to a gyratory crusher, where it is crushed to sizes ranging from pea size to one-half inch in diameter. From the crusher the lime travels, usually by an elevator, to a hopper which feeds the Raymond Mills, where it is reduced to a fine powder. The main feature of the Raymond Mills is the fact that the fine lime is separated from the coarse lime by means of an air current. The Raymond Mill consists of two parts, namely, the grinding part and the separating part. The grinding part is made up of a stationary shell to which is attached a hard steel bull-ring against which a series of rolls run. These rolls are connected to a central rotating shaft in such a manner that when the shaft begins rotating the rolls are thrown against the bull-ring by centrifugal force, and the lime is pulverized by the pressure of the rollers against the bull-ring. A manganese steel plow is located ahead of each roller, and constantly throws a stream of material between the faces of the rolls and the bull-ring. Air enters the bottom of the mill through a series of tangential openings, picks up the more finely ground lime and carries it to the top of the mill proper, where it passes through holes fitted with deflectors into a hopper from which the lime-laden air is carried through a fan and into a cyclone where the fine lime

is deposited and the lime-free air returns to the bottom of the mill. Before the lime-laden air can pass from the hopper into the fan, it must pass through an adjustable sleeve where the coarser particles are thrown out and are returned to the mills for further grinding. If the lime is not fine enough or if the "grit" is too high, this adjustable sleeve is lengthened, while if the lime is very fine and the capacity of the mills is too restricted, the sleeve is shortened. In other words, the regulation of this sleeve forms the main part of the possible regulation of the mills. Lowering the sleeve too much will, however, decrease the capacity of the mills.

To operate these mills successfully the following points must be observed:

(1) The mills must be oiled regularly, and especial care should be taken that the rollers are well greased at all times.

(2) The adjustable sleeves in the upper compartment should be so adjusted that the mills will provide as fine lime as possible and yet produce enough lime to keep the Steffen house up to capacity. By lowering the adjustable sleeve the lime produced will be made finer, but at the same time the capacity of the mill will be reduced. A proper balance between fineness and capacity must be maintained.

(3) The temperature of the mills should be watched, and, if the mills become too hot, they should be shut down and allowed to cool off.

(4) The temperature of the lime going to the crusher should be watched. The lime from the kiln generally has to be floor-cooled before being fed to the crusher, and any attempt to feed hot lime direct to the crusher will usually result in trouble with the mills.

(5) The lime going to the crusher should be inspected for clinkers, flint, and pieces with unburned cores, as these are hard on the mills.

(6) The air piping from the fan to the mills should be kept free from leaks, for, if air leaks in, a certain amount of the lime will be air-slacked and rendered useless for the Steffen process.

After the sugar has been precipitated as saccharate in the coolers, the next step in the process is the separation of the insoluble saccharate from the waste water containing the impurities, and this is accomplished in the saccharate filters. Various types of filters have been used in this service, the more common types being (1) Plate and frame presses, (2) Kelly presses, (3) Vacuum filters, either drum or disc type.

In the previous chapters attention has been called to the im-

portance of securing beet juice of as high a purity as possible, in order that a maximum amount of sugar may be recovered as granulated sugar, and the same reasons that make it desirable to secure a beet juice of high purity make it likewise desirable to secure a saccharate of high purity, for in a Steffen factory this saccharate is introduced into the beet juice at first carbonation and becomes an integral part of the juice from that point on.

Saccharate cake, as ordinarily obtained in practical operation, contains impurities of two classes, namely, insoluble and soluble impurities. The insoluble impurities, which are precipitated as part of the saccharate cake, are absolutely dependent on the type of molasses worked, and so far no commercially practicable method had been discovered by which they can be removed or be prevented from precipitating with the saccharate. The soluble impurities are those contained in the waste water which is not entirely displaced by washing, and, if the cake can be perfectly washed, they can be entirely removed. It therefore is very essential that all the waste water in the cake be displaced in the washing, or, in other words, that as nearly a perfectly washed cake as possible be obtained, and the filter presses should be operated to that end. The degree of washing that has been attained can be judged by comparing the purity of the saccharate cake obtained in the factory with the purity of the "Perfectly Washed Cake" determined by the laboratory, since, if no soluble impurities are present in the cake, further washing cannot increase its purity, and the purity of the saccharate cake and the perfectly washed cake should be the same.

The plate and frame presses used for saccharate are very similar to those used on the first press station, except that in most cases 2-inch mud frames are used for saccharate, instead of 1-inch as on the first presses. The operation of all plate and frame presses is practically the same. The material to be filtered, in this case the finished cooler solution, enters the inside of the mud frame, the saccharate precipitate is retained by the filter cloth, and the waste water filtrate passes through the cloth and goes to the sewer or potash reservoir, or to the hot saccharate heating system. After the mud frames are filled, the valve on the line conducting the finished cooler solution to the presses is closed, and the wash water valve is opened. This water enters through the proper ports into the water plates, passes through the cake and, in so doing, displaces the waste water contained therein, and increases the purity of the saccharate cake by forcing out the waste water containing the impurities. Plate and frame saccharate presses are equipped with two kinds of plates, each connected with a different inlet and outlet

channel. For convenience these are called "A" and "B" plates. It is possible with this arrangement either to introduce the clear water into the "A" plates and force the waste water out through the "B" plates, or to introduce the clear water into the "B" plates and force the waste out through the "A" plates. In order to keep the cloths clean, these two methods should be alternated, first washing from "A" to "B" and then from "B" to "A".

The following points should be observed if good filter press work is desired: The cloths should be in good condition, in order that the filtration may be good and the filtrate kept clear. A cloudy filtrate means that a certain amount of the saccharate is getting through the cloths, and this increases the loss of sugar in the waste water, for, even if the hot saccharate process is used, cloudy waste water causes some increase in the sugar loss.

The machined face of the mud frame must be kept clean and free from cake, or otherwise the press will leak between the frames and it is impossible to do good work with a leaky press. This is a very important point and cannot be emphasized too strongly, for as a general rule one can gauge the quality of the work being done on a press station by the appearance of the station and the condition of the presses as regards leaks.

The presses should not be filled to such a point that the cake formed is too hard, for, if this is done, the cake will be too compact, and it will be extremely difficult to make the wash water pass through it. From many observations it can be said that, for best purity work, the cake should be of such consistency that at the top of the frame it is reasonably soft. The pressure of filling will vary considerably, depending on the age and hardness of the cloth, but it is usually from 35 to 45 pounds. The wash water pressure should be about one-half of the filling pressure, or about 20 to 25 pounds, and the cake should be washed until the wash water coming from the presses is of about 2° Brix. The washing should be done as slowly as possible without delaying the house, for experiments have demonstrated that slow washing makes for high purity. Also, experiments have shown that it is advisable to leave the inlet valve on the wash water line well open, and to gauge the volume of water passing through the press by throttling the outlet valve, since this procedure creates an even pressure throughout the entire press and makes for better and more even washing. It is, however, impossible to use the system of throttling the outlet valve unless the press is in good shape and very tight.

The Kelly presses used for saccharate are identical with those used for first juice which have been described in the chapter on

"Carbonation Filters." The same general rules of operation are also applicable.

Vacuum filters are now coming into common use and are being installed in practically all new plants. There are three types in use, the Oliver, the Portland, and the American. The Oliver and Portland filters are of practically identical construction, and were adopted from the mining industry, where they have been used for a good many years. The American is of the disc type and is of more recent development.

The Oliver and Portland filters are of the continuous, vacuum, drum type, consisting of a drum, or cylinder, slowly revolving on a horizontal axis, with the lower portion submerged in a tank containing the material to be filtered. The filtering medium is stretched over the surface of the drum, which is divided into compartments, it is supported underneath by a screen, and held in place and protected from wear on the outside by wire binding. Each section of the drum is connected to an automatic valve which controls the application of vacuum for forming and washing the cake, and the admission of air for its discharge. Washing is accomplished by a fine spray of water which is directed upon the cake after it emerges from the solution.

The American filter, instead of having the filter cloth stretched over a drum, has cloth covered discs which are divided into segments and connected to the automatic valve. The cake is formed on the faces of these discs. The principle as well as the operation of these filters is practically the same as that of the drum type.

In the operation of these filters, foam collects in the filter tanks, and, if it is sucked into the cloth, the capacity of the filter is reduced greatly. In order to remove the foam, overflows are provided which carry it to a special tank. After the foam is broken up in this tank, the solution is pumped back to the filters. This rehandling causes a certain amount of the saccharate to decompose and redissolve, and so increases the amount of sugar in the waste water. For this reason the amount of overflow should be kept as small as will remove the foam.

Sufficient water should be sprayed on the cake to remove all the non-sugar possible. In actual practice 80 to 100 per cent of wash water on cake is used. The vacuum on the washing sections should be high enough to pull all of the water through, and not so high as to crack the cake before the drying zone is reached. On Oliver and Portland filters the washing vacuum is usually carried between 12 and 15 inches, and on the American filters somewhat higher.

At frequent intervals the cloth becomes so dirty that the capacity of the filter is reduced, and it is therefore necessary to wash the fabric. This may be done at most times with clean hot water with the aid of a scrub brush, but at intervals the cloth should be thoroughly washed with a solution of muriatic acid of about 5 per cent strength.

HOT SACCHARATE PROCESS

After the cold saccharate has been filtered out, there still remains in the waste water a certain amount of sugar which cannot be removed with lime in the cold, and, even under good operating conditions, the sugar content of the cold waste water will be from .4 to .5 per cent. This sugar is probably in the form of di-calcium saccharate, and, upon heating to 75° C. or above, from 70 to 80 per cent of it may be precipitated as hot tri-calcium saccharate. The hot tri-saccharate is then filtered off from the waste water, washed, and added to the process in a similar manner as was the cold saccharate.

In actual practice, however, when operating the hot saccharate process, the lime addition is stopped at such a point that the cold waste water will contain about .8 per cent sugar, and this cold waste water from the presses is then sent to the heating tanks, where its temperature is raised to about 80° C. The heating of the cold waste water has hitherto generally been done by means of direct injection of either exhaust or live steam, but it is possible to do a considerable portion of this heating with the vapors from the evaporators and thereby bring about a considerable coal saving. Some heating may be accomplished in a heat exchanger, in which the heated filtrate from the hot saccharate presses gives up some of its heat to the cold waste water. This heat costs nothing but the interest and maintenance on the heat exchanger. After the heating has been completed, the hot tri-saccharate which has been precipitated is removed by filtration.

Three types of apparatus are now in common use for separating the saccharate from the hot waste water, namely, plate and frame presses, Vallez presses and the combination of Dorr thickeners with vacuum filters.

The operation of the plate and frame presses is the same as when used for cold saccharate. These presses are not suitable for hot saccharate work for the reason that the hot waste water very quickly destroys the filter cloth, causing an extremely high expense for fabric.

The Vallez filter consists of a series of rotating discs, covered on each side with the filtering medium (Monel metal cloth, when used for hot saccharate) and communicating with a hollow, central driving shaft, the whole being contained within a cylindrical shell. The shell is filled with the solution to be filtered under pressure, which forces the filtrate through the filtering medium and out through the hollow shaft, leaving the cake adhering to the outside of the discs. When sufficient cake is formed, wash water is forced into the shell and displaces the waste water in the cake. For discharging, a scroll in the bottom of the apparatus carries the cake as it falls off the discs, to a door which discharges into the saccharate scroll. To prevent the cloth from becoming scaled up, the press is coated, before filtration is begun, with a mixture of lime cake and Kieselguhr which is washed off with the cake and removed in the first carbonation. For this coating solution the second press cake is mixed with a small amount of water and run to the coating solution tank in the Steffen house, where it is diluted to approximately 35° Brix by means of hot Steffen waste water, and, for every 2,000 pounds of second press cake used, 50 pounds of Kieselguhr is added. This solution is next thoroughly mixed and heated to 60 to 80° C., and is then ready for use.

In the more recent hot saccharate installations, Dorr thickeners with vacuum filters are being generally used. The Dorr thickener is a settling tank with a gently sloping bottom, and is provided with a rotating mechanism which moves the settled solids to a point of discharge in the center, allowing the clear filtrate to overflow. The thickened sludge is removed from the thickener by means of diaphragm pumps. From there it flows to the vacuum filters, the operation of which is the same as described for cold saccharate. The operation of the thickener is absolutely automatic and continuous, and consequently requires very little attention. The most important point is the method of heating the saccharate. If the heating is done unevenly or too rapidly, the precipitate will not settle and a cloudy overflow will result. In general practice the sludge pumped from the bottom of the trays should be about 12° Brix.

The saccharate from both the cold and hot filters is conveyed to the saccharate mixers, where it is diluted to about 30° to 33° Brix with sweet water and heated to between 85° and 90° C. From these mixers it is pumped to the first carbonation station, where the lime defecates the juice and the sugar goes into the main process.

SECTION B

Sugar and lime unite to form three different compounds, mono-calcium saccharate, di-calcium saccharate, and tri-calcium saccharate. Mono-calcium saccharate is a compound of one molecule of sugar with one molecule of lime, the proportion by weight being 16.4 per cent lime on sugar. It is formed by dissolving sucrose and fresh, finely powdered quick lime in equal molecular proportions in water at a low temperature. If additional lime is added until two molecular parts of lime to one of sugar have been introduced, the di-saccharate will be formed. By weight, 32.8 per cent lime on sugar is required to form the di-saccharate. Both of these compounds are soluble in water.

If still more lime is added, some of it will unite with the di-saccharate and form the tri-saccharate, which is, for practical purposes, insoluble in water and is the compound found in the cold saccharate cake. It is composed of three molecules of lime with one of sugar, and in the pure tri-saccharate there is 49.2 per cent lime on sugar by weight. Theoretically then it is necessary to use in the Steffen process only about 50 per cent of chemically pure lime on sugar, but in actual practice it is found necessary to use a considerable excess, from 80 to 130 per cent lime on sugar, to obtain the maximum precipitation. By experiments, the amount of sugar precipitated by various quantities of lime has been determined and is shown graphically on Plate No. 24.

It will be noted from this chart that, at 5° C., sugar starts to precipitate when about 30 parts of lime to 100 parts of sugar have been added, that from this point until about 80 parts have been added the precipitation is quite rapid, and that beyond the point of 80 per cent lime addition the rate of precipitation gradually becomes slower until at 110 per cent lime addition no more precipitation takes place. The points at which the various changes take place will of course vary with different conditions, but the general nature of the curve will remain the same. The first lime added to the solution probably unites immediately with the sugar to form the mono-saccharate until almost all of the sugar molecules are combined each with a molecule of lime, then, as more lime is introduced, some of the lime molecules, being unable to find a molecule of free sugar, unite with molecules of the mono-saccharate to form the di-saccharate. Other molecules of lime will find some free sugar and form more mono-saccharate. This continues until almost all of the sugar is in the form of the di-saccharate, when the lime molecules, having difficulty in finding a sugar or mono-saccharate

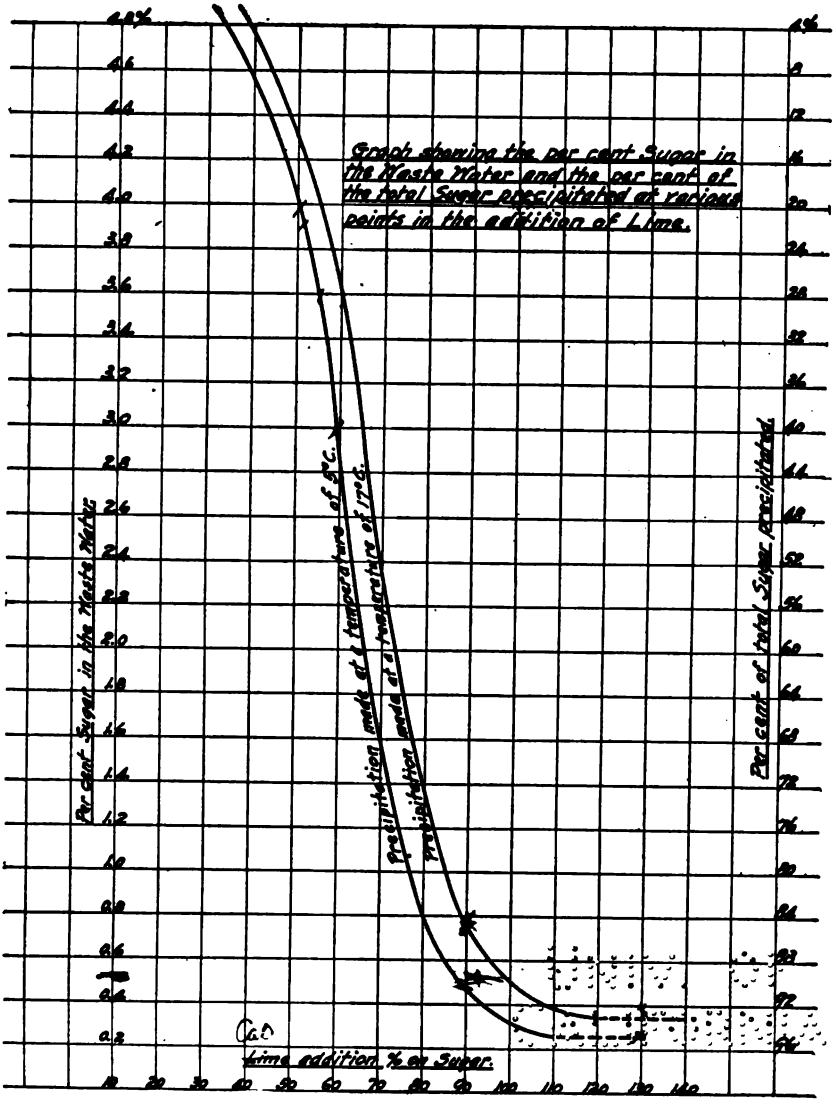
molecule with which to unite, attach themselves to the di-saccharate and form the tri-saccharate. Other particles of lime do not come in contact soon enough with any sugar, or mono- or di-saccharate, and instead unite with the water to form calcium hydrate, thereby being rendered useless as far as precipitating sugar is concerned. This condition, with the greater portion of the lime uniting with the di-saccharate and the smaller portion uniting with the water, continues until the number of di-saccharate molecules is so decreased that the lime has difficulty in coming in contact with them and the greater part of the lime goes into the hydrate. This is the point at which the curve begins to assume the horizontal position. From here on more and more of the lime goes into the hydrate, until at a certain point no more precipitation of sugar takes place and all of the additional lime combines with the water.

There are two fundamental requirements for good Steffen house work; first, the precipitation of the maximum quantity of sugar with a minimum quantity of lime; and second, the greatest possible separation of the sugar from the non-sugars. While these are more or less interrelated, they may conveniently be treated separately, and will be discussed in the order named.

Before the molasses is introduced into the cooler it is diluted to a solution of about 5 to 7 degrees Brix, and the method of making up this solution constitutes the first important factor of Steffen work. The concentration of the cooler solution has a decided influence on the lime addition. Experiments, illustrated graphically on Plate No. 25, have been carried out which show that the amount of sugar precipitated with a given lime addition steadily increases as the concentration of the solution increases until a sugar content of about 8 per cent is reached. In practical operation, the difficulty of filtering the material from the finished coolers, as will be discussed later, renders such a high concentration undesirable, but it is well to remember that a solution of too low density increases the lime addition and also the sugar loss.

In most Steffen houses wash water from the filters is used for making up the cooler solution, and experience has shown that the use of such wash water does not materially increase the lime addition. The addition of waste water does, however, materially increase the amount of lime necessary to precipitate the sugar. If the filter presses leak, some saccharate cake goes with the wash water into the cooler solution. An appreciable quantity of this will increase either the lime addition or the sugar loss. Pan drips from under plate and frame presses, which consist of waste water and sac-

Plate No. 24.


Graph showing the per cent Sugar in the Waste Water and the per cent of the total Sugar precipitated at various points in the addition of Lime.
Per cent Sugar in the Waste Water
Per cent of total Sugar precipitated
Precipitation made at a temperature of 8°C.
Precipitation made at a temperature of 17°C.
Lime addition % on Sugar.
CaO

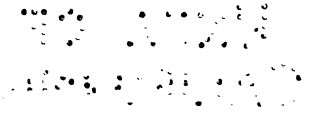
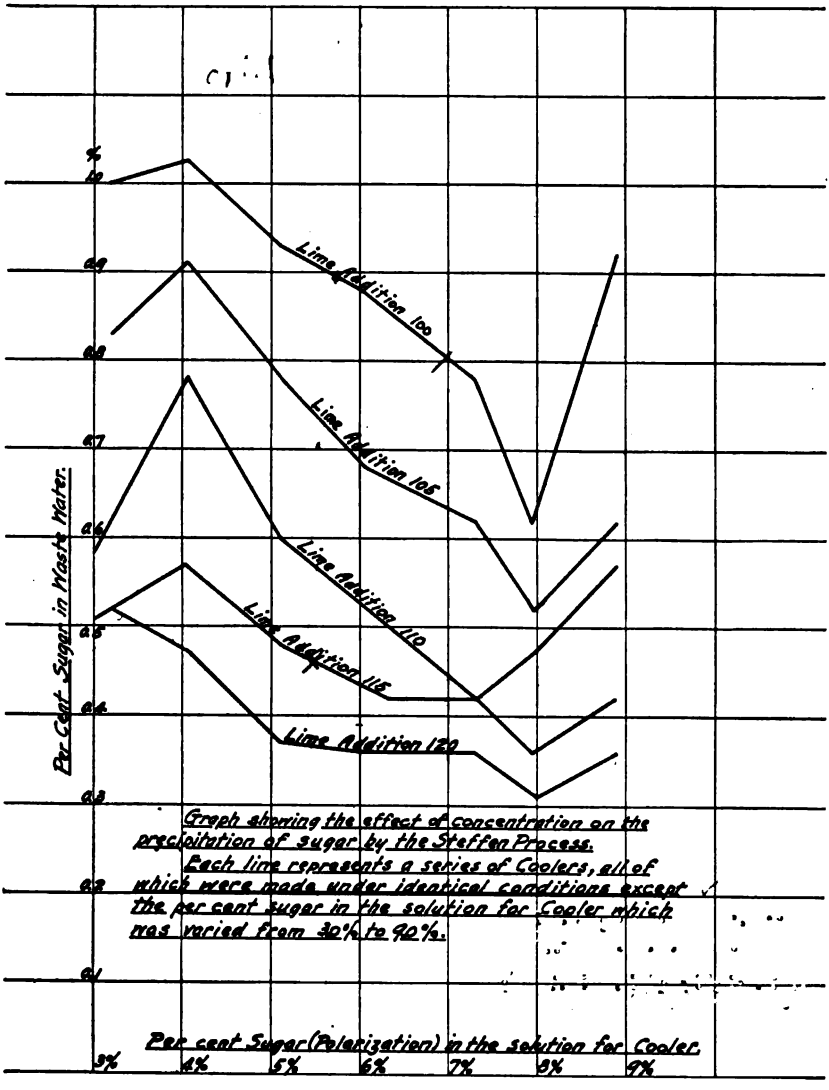


Plate No. 25.



Graph showing the effect of concentration on the precipitation of sugar by the Steffen Process. Each line represents a series of Coolers, all of which were made under identical conditions except the per cent sugar in the solution for Cooler which was varied from 30% to 90%.

charate, are usually taken back into the cooler solution, and, when excessive, are a serious hindrance to good cooler work.

The quality and physical condition of the lime have an important effect on the cooler work. At present two tests are in common use for indicating the quality of the lime; they are "Loss on Ignition" and "CaO by Titration". The loss on ignition indicates the amount of carbon dioxide and water present in the burned lime, and an excessive loss of weight on heating therefore indicates either that the rock has been incompletely burned, or that the lime has absorbed moisture after burning. Either condition reduces the efficiency of the lime in the cooler. When the loss on ignition is more than 2 per cent it should be considered excessive, and steps should be taken to remedy the trouble.

The percentage of calcium oxide present in the lime is determined by the quality of limestone used. As was explained in the chapter on Lime Kilns, a stone of 98 per cent calcium carbonate will theoretically give a lime of 96.6 per cent calcium oxide, while a rock of 95 per cent calcium carbonate will produce a lime of 91.8 per cent CaO. However, the amount of CaO as indicated by the titration test does not tell the amount of lime available for combination with the sugar because some of the lime is already united with other substances, viz., CO_2, water, etc., and because other alkalies, such as magnesium oxide, carbonate, or hydrate, may also be present in the lime and react in the titration test in the same manner as the calcium. But it may be usually stated, that the higher the CaO content of the lime, the more suitable it is for Steffen work.

The chemical activity of the lime, or the ease with which it will unite with the sugar, also varies, and influences the extent to which the sugar is precipitated. This chemical activity varies with the rock and also with the method of operating the lime kiln, overburned rock being less active than that not subjected to such a high temperature.

The lime used in the cooler should be finely pulverized to be efficient. The reason for this is probably that a greater area is exposed to the sugar. If the lime is too finely divided, it will "ball up" and so really reduce the area. In general practice the size of the lime particles should be even, and of such a size that 98 per cent will pass through a screen having 200 meshes to the linear inch.

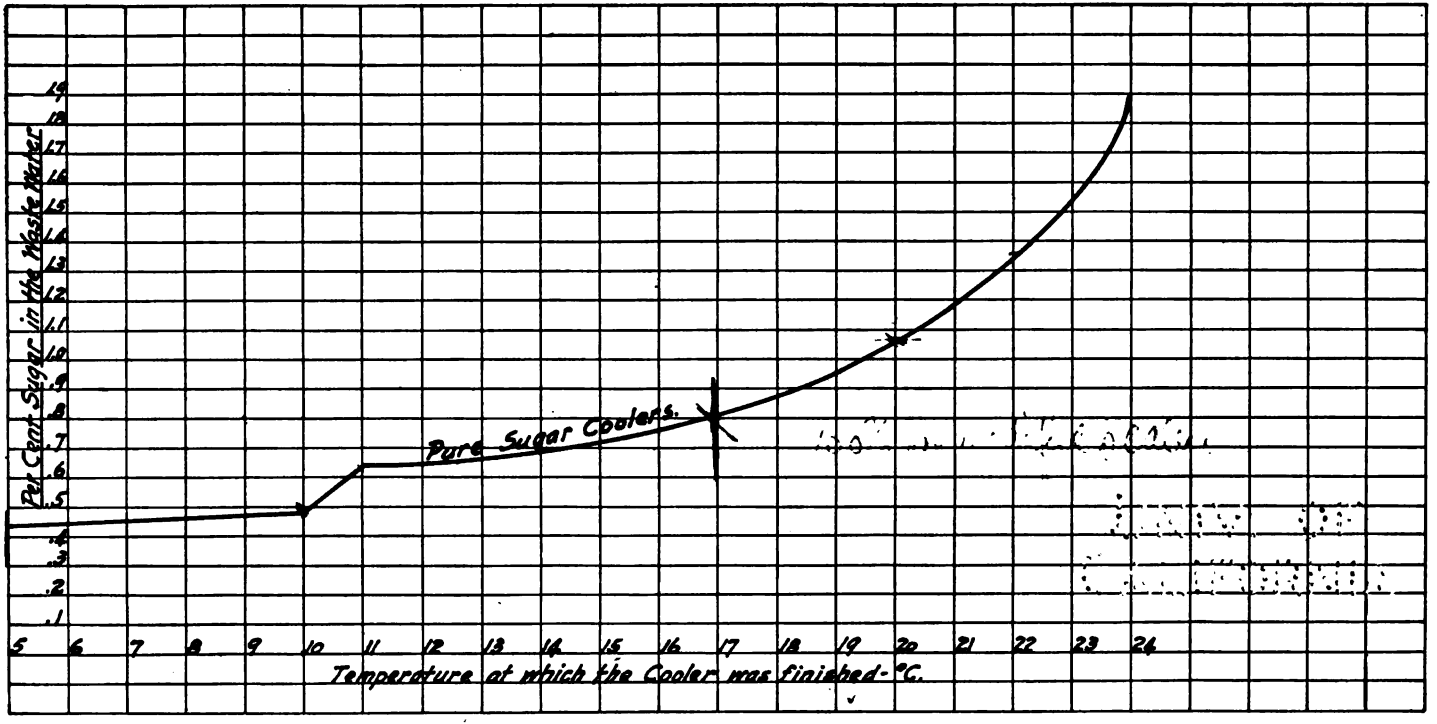
The temperature at which the cooler solution is held during the time that the lime is added has a considerable influence on the

quantity of lime needed to reduce the waste water to a definite sugar content, and the higher this temperature, the more lime will be needed. Plate No. 26 shows in a graphical manner the effect of temperature upon the sugar in the waste water when the same quantity of lime is added. From the graph it will be seen that 11° C. and 17° C. are critical temperatures, that is, there is a sharp increase in the percentage of sugar in the waste water when the cooler is finished at these temperatures compared to slightly lower temperatures. This is particularly true of the 17° C. temperature, above which the precipitation grows more and more difficult. At the range of temperature between 12° and 17° C., one degree increase in temperature will increase the lime needed from 1 to 1½ per cent, or five degrees increase in temperature will increase the lime needed from 5 to 8 per cent, while above 17° C. the effect of each degree increase in temperature is greater on the lime addition than when the temperature is below 17° C.

The length of time taken up by the addition of the lime also has an influence on the amount of lime required; the longer the time, within reasonable limits, the greater is the efficiency. This is due to the fact that an appreciable length of time elapses after the lime is added before it hydrates, and the lime particles may travel a considerable distance to find sugar with which to unite. The less excess, therefore, of lime there is in any locality, the more chance will there be for it to unite with the sugar, and a slower addition of the lime means less excess in any one place. Further agitation after the lime addition is complete has a similar effect, and will reduce the sugar in the waste water slightly.

The more rapidly the solution circulates in the cooler, so long as too much foam is not formed, the more efficient will be the action of the lime, because the particles of lime will readily find the sugar with which to unite. The violence of agitation and the time element are more or less interchangeable; a short time factor may be partially compensated for by a greater speed of circulation and a slow circulation by allowing more time. The circulation is dependent upon the type of propeller, the speed at which it revolves, its location in the cooler well, and the height of the solution in the cooler. The cooler propeller in common use is 36 inches in diameter with four blades of 36-inch pitch. This type has been in use a great many years, but it is not improbable that some other type might do better. About 180 R. P. M. has been determined experimentally to be the best speed at which to run this type of propeller. The best location for the propeller has been found by experiment to

Graph showing the effect of temperature on sugar precipitation.



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be the position in which it is half inside and half outside the well. The best height to which the cooler should be filled may be determined experimentally, and, after having been determined, should be rigidly adhered to. It should be the point at which the maximum movement is observed on the surface of the liquor, and at the same time no air is sucked into the well, and this should represent the point when, other conditions being the same, the lowest lime addition is obtained.

The tri-calcium saccharate formed in the coolers is separated from the waste water at the cold filtration station. Before washing, the cake contains two kinds of impurities, those in solution in the waste water, and those precipitated with the lime and sugar in an insoluble form. The soluble non-sugars may all be removed with perfect work, but the insoluble ones are carried into the juice with the sugar and finally find their way to the molasses. The purity of the "Perfectly Washed" saccharate cake represents the purity of the cake after all the soluble non-sugars have been removed.

The amount of inseparable non-sugars depends entirely on the nature of the molasses worked and cannot be controlled after the molasses is introduced. The quality of the non-sugars in the beets determines the inseparable non-sugars in the molasses produced from the beets and therefore the purity of the "Perfectly Washed" cake made from straight beet molasses, or, as it is commonly called, "Foreign Molasses". Molasses produced at a Steffen factory may be regarded as composed of molasses produced directly from the beets and additional molasses produced on account of the non-sugars introduced with the saccharate. If the saccharate has been perfectly washed, it may be assumed that none of the non-sugars introduced with it can be separated either in the main house or the Steffen process. Therefore, the greater the percentage of this "Molasses from Molasses" there is in the molasses worked, the lower will be the true purity of the "Perfectly Washed Saccharate".

In the districts in which the Great Western Sugar Company operates, one may expect to produce from straight beet molasses a saccharate of about 90 true purity, and, from molasses produced on account of impurities introduced with the saccharate, practically no non-sugars are eliminated, and therefore a saccharate of a purity approximately the same as the purity of the molasses is produced. By calculation it has been found to be about 64 true purity. Knowing then the percentage of "Molasses from Molasses"

in the molasses worked, one may calculate within reasonable limits the true purity of the "Perfectly Washed" saccharate cake.

When "Home Molasses" is being worked, the inseparable non-sugars are returned to the Steffen house until their quantity becomes so great as to make the production of saccharate cake of a reasonable purity absolutely impossible. Also on account of the increased quantity of non-sugars to be handled in the sugar end, the main house is usually slowed up. When this condition is reached, the proper procedure is to discard the molasses produced and work foreign molasses in the Steffen house. The amount of inseparable non-sugars then determines the working qualities of molasses. At present there is no analysis showing this directly, but it has been found by experience that it is indicated to a quite accurate degree by the percentage of the so-called "Raffinose"; the higher the "Raffinose" content, the higher is the percentage of inseparable non-sugars.

The soluble non-sugars may all be removed from the cake by washing, but certain conditions make their removal more difficult. If the concentration of the cooler solution is too high, the viscosity of the waste water is increased and therefore its displacement rendered more difficult. With a solution containing not more than six, or six and one-half per cent sugar, no difficulty should be perceived in washing. A solution made with wash water produces a saccharate harder to wash than one made with pure water, and the use of waste water in the solution very greatly reduces the ease of washing. Experience has shown that, if the lime used is too finely divided, the cake washes with difficulty, also that an increase in the amount of lime used will often decrease the difficulty of filtering and washing.

The cold waste water contains lime and sugar in solution in such a condition that, on heating, the hot insoluble tri-calcium saccharate is formed. The hot tri-saccharate is similar in composition to that formed in the cold except in the number of molecules of water combined with the sugar and lime. The physical properties are, however, somewhat different.

It has been thought until recently that the sugar in the cold waste water exists in the form of either the mono- or di-saccharate and that the heat breaks up the mono-saccharate into two molecules of free sugar and one molecule of the tri-saccharate, and the di-saccharate into one molecule of free sugar and two of the tri-saccharate. If this were the case, it would be possible to precipitate only two-thirds of the sugar originally in the waste water, but in

actual practice more than this is often precipitated, and under experimental conditions all of the sugar has been removed. Also, the cold waste water has in solution more than sufficient lime to form the di-saccharate with all of the sugar present. From the above it is apparent that the sugar and lime do not exist wholly as the simple mono- or di-saccharate; in just what form they do exist is not known.

It has been observed that, with a given molasses, the alkalinity of the hot waste water is constant regardless of the alkalinity or sugar content of the cold waste water, and that it is usually about .40 per cent, about two-thirds being due to lime and one-third due to the other alkalies from the molasses. The amount of lime in the cold waste water which is available for uniting with the sugar is therefore represented by the difference between the alkalinity of the cold waste and that of the hot, and the relation between this "Available CaO" and the sugar in the cold waste water determines the amount of sugar which can be precipitated. It has been found out experimentally that, when there is 77 per cent or more available CaO on sugar in the cold waste water, all of the sugar can be removed by heating.

The operation of the Steffen house should then be such as to give the greatest possible ratio of available CaO to sugar, and the three factors which to a large extent govern this are the cooler temperature, the violence of agitation, and the length of time taken in adding the lime. The conditions which give the most efficient precipitation of sugar in the cold, i. e., low temperature, rapid circulation, and slow lime addition, yield also the greatest precipitation in the hot. The extent to which the heating should be carried to obtain the maximum precipitation varies somewhat with the molasses worked, but generally speaking a temperature of 85° C. is sufficient.

In general the remarks made in connection with the purity of cold saccharate apply in the case of hot saccharate. In addition, the method of heating greatly affects the ease with which the hot cake can be washed. Instantaneous or quick heating after a temperature of about 60° C. has been reached, at which temperature the tri-saccharate starts to precipitate, gives a cake very difficult to filter and wash and practically impossible to settle in a Dorr thickener. At least ten minutes should be allowed for bringing the waste water up to the desired temperature.

For good work the precipitation by the hot saccharate process should be at least 70 per cent of the sugar present in the cold waste

water, and, if this is accomplished, it will be seen that, if the amount of sugar in the cold waste water is .8 per cent, the hot waste water should not contain over .24 per cent sugar.

The losses from a well operated Steffen house may vary from 2½ per cent on sugar in molasses in a house equipped with the hot saccharate process, to 6 per cent on sugar in molasses in a house not so equipped. This loss depends on two factors, the percentage of sugar in the waste water, and the quantity of waste water made. The percentage of sugar can be regulated by varying the lime addition, temperature, agitation, etc., and the quantity of waste water can be regulated by varying the density of the cooler solution, by taking back more or less waste water, and by general care throughout the process. The quantity of waste water should be about 250 cubic feet per ton of molasses worked when operating the hot saccharate process. If more than this is made, the loss is too great, while, if less is made, it is probable that too much waste water is being taken back to dilute the molasses, and the quality of the cold saccharate will suffer.

PROBLEMS

Example

The sugar lost in the waste water is calculated by the following formula:

$$P = .000312 \times W \times S$$

Where P = Tons sugar lost
W = Cubic feet of waste water
S = Sugar in waste water (Grams in 100 cc.)

Thus if 150 tons of molasses are worked per day and the waste water made is 250 cubic feet per ton of molasses and has a sugar content of .30, the tons sugar lost may be calculated as follows:

W = Cubic feet waste water = $150 \times 250 = 37500$
S = Sugar in waste water = .30
$P = .000312 \times W \times S = .000312 \times 37500 \times .30 = 3.42$ Tons.

(1) How much sugar will be lost in the waste water per campaign if 15,242 tons of molasses are worked, the waste water per ton of molasses is 252 cubic feet and the sugar in the waste water is .32?

How much sugar will be lost if the sugar is reduced to .26?

How much sugar will be lost if the waste water is 278 cubic feet per ton of molasses and the sugar is .32?

CHAPTER NO. XII

EXTRACTION

Any one who has spent much time in a sugar factory recognizes that an important part of the work of the Chemical Department consists in the calculation of the Extraction Statement and the obtaining of the necessary data for it. It is the object of this lecture to explain the nature and importance of "extraction", and, without going into much detail, to give a general idea of the manner in which the Extraction Statement is made up.

MEANING OF EXTRACTION

When a manufacturing process deals with one or a limited number of raw materials which lend themselves to accurate chemical analysis, and yields a purified, or refined, product, it is comparatively simple, if the weights and analyses are known within a reasonable degree of accuracy, to calculate the percentage yield of the refined product, which is what is meant by extraction, and is used to measure the efficiency of the manufacturing process.

For example, in a metallurgical plant which introduces a certain amount of copper, or silver, gold, etc., in the ore, one can readily calculate from the weights and analyses of the raw and the refined material what percentage of the various metals has been extracted.

The beet sugar manufacturing process deals with the single item of sugar, which is introduced in the beets and is obtained in the form of refined, 100 per cent pure sugar. The process of sugar making is, however, attended with losses of sugar which to some extent cannot be economically avoided; a considerable amount of the sugar also goes out in the form of molasses, and, to the extent that these losses occur, the extraction is correspondingly reduced.

Extraction in the sugar industry may then be defined as that percentage of the sugar in the beets sliced which is recovered in the form of granulated, and may be calculated by dividing the pounds of granulated produced by the pounds of sugar in the beets sliced. For example, if a factory slices 100,000 tons of beets containing 15.91 per cent sugar and produces 245,650 bags of granulated, the pounds of sugar in the beets sliced is $100{,}000 \times .1591 \times$

2000 = 31,820,000 and the pounds of granulated produced is 245,650 × 100 = 24,565,000. The extraction is then:

$$\frac{24{,}565{,}000 \times 100}{31{,}820{,}000} = 77.20\%$$

In practice the computation is, for various explainable reasons, more complicated. Further, the above figure tells us only that 100.00 — 77.20 = 22.80 per cent of the sugar in the beets has been lost or has disappeared in some manner. It is therefore customary to calculate the amount of sugar which goes out in the molasses, and the amounts which can be estimated as lost at the various stations where such losses are known to occur. When all such known losses have been accounted for, there remains an unexplainable loss which is designated as the "unknown" or "unaccountable" loss. The amounts and percentages of all these losses are set forth on the Extraction Statement, and by an inspection of the various items it is possible to determine what losses are high and where investigation should be concentrated.

IMPORTANCE OF EXTRACTION

It follows that "extraction" is the opposite of "losses", and that "increasing extraction" means the same thing as "decreasing losses".

The importance of extraction may be seen from the following example. A variation of one point in extraction between factories working beets of the same quality is not unusual. Let it be supposed that, in the example in the preceding section, the extraction had been increased one point, or to 78.20. The yield of granulated would then have been 31,820,000 × 78.20 = 248,832 bags, and 248,832 — 245,650 = 3,182 additional bags of sugar for every 100,000 tons of beets sliced.

All intelligent efforts to reduce losses and increase extraction will pay for themselves many times over even if the results are small, and, when one considers how many places there are in a sugar factory where losses can occur, it is plain there is an almost unlimited opportunity and incentive to improvement, from tightening up an ordinary leak to developing better methods of installing and operating the various stations.

One must recognize the fact, however, that extraction is a measure only of the quality of work and has nothing directly to do with capacity, which is a measure of the quantity of work done in a unit of time. At times these two aims may conflict, for exam-

ple, an increase in slicing may be attended with higher battery losses, etc., and it is necessary to strike a proper balance; this is a case where the ability to figure such a problem is of the greatest value. However, while this is sometimes the case, it must also be recognized that improvements in both capacity and extraction frequently go hand in hand.

CLASSIFICATION OF LOSSES

Losses are divided into three principal classes as follows:

(1) The known losses (exclusive of molasses) which are further subdivided:
   (a) Loss in pulp and pulp water.
   (b) Loss in lime cake.
   (c) Loss in filter cloth washing.
   (d) Loss in Steffen waste water.
(2) The molasses loss.
(3) The unaccountable loss.

While these have all been referred to in previous chapters, this is an appropriate place to review and describe them.

TOTAL LOSSES

The total losses are equal to the *sugar in the cossettes minus the granulated produced.

*If a Steffen factory works more molasses than it produces, the amount of sugar in the additional molasses worked must be added to the amount of sugar in the cossettes.

KNOWN LOSSES

Pulp and Pulp Water.—The first place where a known loss occurs is in the batteyr, as a certain amount of sugar is left in the pulp and pulp water. As the sugar is determined every hour, a very close control can be maintained. The pulp and pulp water are each considerd to amount to 100 per cent on beets in weight. It is important that the sample be properly taken and that the work of the man under the battery in this respect be supervised by the laboratory.

A sugar content of .18 — .20 in the pulp, and .08 — .10 in the pulp water, is considered normal, though some factories get lower figures.

Lime Cake.—The filter press station is one place where large losses often occur and should be carefully watched at all times. It

is by no means an easy thing to obtain an accurate lime cake sample, especially from Kelly presses, and even where the cake sample is correct, there is always the additional possibility of leaks into the hopper. The sample of "lime sewer" enables the total loss at the press station to be checked up, and this test should be just as much watched as that of the lime cake. As the "lime sewer" sample is diluted to an unknown extent, the percentage of sugar in it cannot be directly compared with that of the cake, so the comparison is based on the ratio of "parts of sugar to 100 parts of CaO." If the ratio in the sewer sample essentially exceeds that of the cake, it signifies that additional sugar is being lost which was not originally present in the cake, and juice leaks should be looked for.

The weight of cake was formerly obtained by weighing individual cakes. From this was calculated the average weight of one press, and the latter was multiplied by the number of presses reported dumped to get the total amount of cake. This method cannot be used with Kelly presses and is open to various objections with plate and frame presses, so the amount of cake is now obtained from the weight of lime introduced, and the percentage of CaO in the lime and in the lime cake. For example, if a factory introduces 30 tons of lime containing 91 per cent CaO, the tons of CaO in the lime cake is $30 \times .91 = 27.3$. If the cake analyzes 20.2 per cent CaO, the amount of cake is $27.3 \div .202 = 135$ tons. The amount of sugar lost in the cake is then calculated by multiplying the weight of cake by the average percentage of sugar.

With good work the percentage of sugar in the lime cake should be reduced to .6 — .8 without the use of an excessive quantity of wash water.

Filter Cloth Washing.—This loss is small, compared to the others, but may, if neglected, easily run into considerable money. Few factories are equipped to obtain absolutely accurate measurements of the filter cloth wash water, but any abnormal figures will indicate the need of investigation.

Steffen Waste Water.—At Steffen factories the loss in the Steffen waste water is one of the large known losses. To determine this it is necessary to know first the weight or volume of the waste water. Efforts made in the past to measure this directly in tanks or by meters have not proved very successful on account of the large amount of foam which is always present. This figure is obtained now by metering all the water which enters the Steffen

house, in the coolers and presses, and making a few necessary corrections. The formula reads: Cubic feet of waste water = (cubic feet of water metered to Steffen House) plus (cubic feet of water introduced in molasses) plus (cubic feet of water in steam injected to heat the cold waste water) minus (cubic feet of water left in saccharate cake). The percentage of sugar, which is determined every hour, completes the needed information.

The percentage of sugar in the molasses worked which is lost in the Steffen waste water shows directly what the actual loss is in the Steffen house, and is the best figure to use for comparative purposes. The reduction of this loss depends on the efficiency of the precipitation in both the cold and the hot process, and on good filtration. As stated in the lecture on the "Steffen Process", the loss of sugar in a well operated Steffen house equipped with the hot saccharate process should not exceed 2½ per cent.

MOLASSES LOSS

By the "molasses loss" is meant, at a non-Steffen factory, the amount of sugar in the molasses produced, and, at a Steffen factory, the amount of sugar in the molasses produced but not worked, i. e., the difference between the sugar in the molasses produced and worked. (If the sugar in the molasses worked exceeds the sugar in the molasses produced, there is no molasses loss.)

The molasses loss differs from all other losses in that in those losses the sugar is lost and gone forever, while the sugar in the molasses produced has been merely converted into a less valuable by-product, which still has monetary value. However, for the purpose of the Extraction Statement, the sugar in the molasses is with reason classified as a loss.

Owing to the necessity of "discarding" so much molasses, the molasses loss is by far the largest of any of the individual losses; it constitutes almost exactly half of the total losses of the factories as a whole.

It has been explained previously that the molasses production depends solely on the purity of the thick juice and of the molasses. The molasses loss may therefore be reduced:

(1) By improving the elimination, so as to obtain thick juice of higher purity.
(2) By reducing the molasses purity, so as to leave less sugar in the molasses.

To which may be added:

(3) By working more molasses in the Steffen House.

UNACCOUNTABLE LOSS

When all the determined losses have been totaled and deducted from the total loss, there remains an unexplainable loss which is designated as the "unaccountable loss".

This is obviously the most difficult loss to investigate and to control, because it may occur in so many places and in different places at different times. If one is dealing with a high lime cake loss, it is usually not difficult to discover the reason and to determine how much improvement can be made under the prevailing conditions, but when one is confronted with a high unaccountable loss, it requires a thorough search of the factory from one end to the other. Sometimes great difficulty has been encountered in locating the source of unaccountable losses, while at other times the search has been rewarded with important discoveries.

Unaccountable losses may be classified as follows:

(1) Actual destruction of sugar.

(a) By caramelization. Caused by overheating on exposed tubes and heating surfaces.

(b) By inversion and fermentation. Caused by allowing the juices to become acid and by keeping them too long in storage. Thin juices deteriorate much more rapidly than thick juices.

(2) Destruction of polarization, but not of sugar.

By this is meant that the polarization of certain optically active non-sugars is changed during the manufacturing process, resulting in an apparent, but not a real, unaccountable loss. We have very little definite information about this, but it is probably not great and is comparable between factories. It is generally recognized that there is a small "polarization loss" during carbonation. Experiments made at Fort Collins indicate that this amounts to about 1 per cent of the diffusion juice polarization.

(3) Mechanical losses.

(a) By entrainment, i. e., carried over mechanically from the boiling juices in pans and evaporators. This may be small and con-

tinual, or come occasionally in large "shots". The condensed water tests should be watched closely to control this.

(b) Losses in press troughs, sewers, etc.

(c) Leaks in general from juice lines, tanks, etc.

It should be remembered that a very small, continual leak may result in the loss of much more sugar than a large, spectacular loss such as the boiling over of a pan, and efforts should be made to keep all pipe lines and apparatus absolutely tight.

An unaccountable loss which much exceeds 0.4 per cent on beets is considered abnormal.

OTHER POINTS OF LABORATORY CONTROL

For the purpose of the Extraction Statement, it is equally important to have accurate figures on a number of other things, e. g., the weight and polarization of the beets and of the molasses, and the count of sugar in the warehouse. Both the weight and the polarization of the beets are checked very carefully and these are probably among the most accurate of the control figures. The molasses gives a good deal of trouble; sometimes the main house weights are found to be in error, and more frequently the Steffen House weights are inaccurate. The Steffen House men can be of great assistance if they will aim to furnish accurate weights of the molasses. Discrepancies in the molasses weights are checked by measuring the amount of molasses on hand, but it is desirable to obtain accurate figures every day and to avoid the necessity of such corrections.

THE INVENTORY

If a factory starts a campaign without any process sugar on hand, and ends the campaign without any raw sugar or sugar in process, the campaign extraction may be calculated as simply as was done in the early part of this lecture. In practice, however, such process sugars are encountered and have to be taken account of, and also, during the campaign, extraction statements have to be figured for shorter periods at times when the house is full of juice and the manufacturing process is not interrupted.

Whenever an Extraction Statement is to be figured, an inventory of the sugar in process must first be taken. The procedure is precisely analogous to that of a merchant who, in order to obtain figures on his year's business and profits, takes an inventory of his goods, credits the total value to the current year's business, and charges it against the following year's business.

All juices in the house are accordingly measured, and the necessary laboratory tests are obtained if they are not already on record. Juices of different purity will yield varying amounts of granulated sugar and molasses, so this is taken into consideration in suitable formulas, and the finished calculation shows the amount of "granulated" and of "sugar in molasses" which will be obtained from each product, and the total for each of the two items.

It is important that the measurements of thick juices and massecuites be especially accurate, because even a small error in the case of such concentrated material will represent considerable sugar. The crystallizers, mixers, and pan floor tanks can always be accurately measured. The measurement of liquors which have gone into unfinished pans offers some difficulty. Sugar boilers can help by keeping accurate account of what liquors they have taken into pans on "stock days", and should not object, if the pan is not at a critical stage, to interrupting the boiling in order that the contents of the pan may be accurately measured before a sample is taken.

While the inventory furnished only two figures for the Extraction Statement, its preparation and calculation is a large part of the actual work required in the making up of the report.

THE EXTRACTION STATEMENT

Extraction Statements in this company are made out on the 1st and 16th of every month.

An example of a very much condensed Extraction Statement for a non-Steffen factory is given on page 247. The method of calculation should be clear from the explanation that has been previously given. After the balance has been made on the basis of "pounds of sugar", percentages for each item are then figured on the weight of beets and on the amount of sugar in the beets. In the example given, the unaccountable loss, per cent on beets, is

$$\frac{416788 \times 100}{70855 \times 2000} = .29$$

and the extraction, per cent on sugar, is $\frac{18137870 \times 100}{22843652} = 79.40$

In actual practice, the calculation of the Extraction Statement is much more complicated, because of the necessity of taking into consideration other things, such as the amount of sugar in process at the beginning and the end of the run, for the computation of which the inventory is taken. Nor are the intermediate steps, by which the various figures are derived, explained in detail. The example used, however, is sufficient to give a general idea of the computation and the nature of the Extraction Statement.

EXTRACTION STATEMENT

Beets sliced: 70,855 tons, of 16.12 per cent sugar and 84.2 purity.

	Pounds	Pct. on Beets	Pct. on Sugar	Pounds	Pct. on Beets	Pct. on Sugar
Sugar in cossettes	22,843,652	16.12	100.00			
Net granulated produced (extraction)	18,137,870	12.80	79.40			
Total losses				4,705,782	3.32	20.60
Loss in pulp	269,920	.19	1.18			
Loss in pulp water	150,120	.11	.66			
Loss in lime cake	113,180	.08	.50			
Loss in filter cloth washing	128	.00	.00			
Total known losses (exclusive of molasses)	533,348	.38	2.34			
Sugar in net molasses produced	3,755,646	2.65	16.44			
Total known losses (including molasses)				4,288,994	3.03	18.78
Unaccountable loss				416,788	.29	1.82

Actual extraction (as shown above) 79.4

Standard extraction (from chart on plate No. 27) 81.9

Performance factor $\frac{79.4 \times 100}{81.9}$ 96.9

STANDARD EXTRACTION AND PERFORMANCE FACTOR

A comparison of the Extraction Statements of two factories will show at a glance which factory has obtained the higher extraction, but it will not necessarily indicate which factory has done the better technical work. Assume, for example, that factory "A" has obtained the results given in the Extraction Statement on page 247, i. e., that it has obtained an extraction of 79.4 with beets of 16.12 per cent sugar and 84.2 purity. If another factory has obtained an extraction of 77.9 with beets of approximately the same purity and sugar content, there is no doubt as to which factory has done the better work.

Suppose, however, that a factory, which will be designated as factory "B", has obtained an extraction of 77.9 with beets of 15.0 per cent sugar and 83.6 purity. Plainly, under a fair appraisal, factory "B" could not be expected to obtain as high an extraction as factory "A", because some allowance must be made for the poorer quality of the raw material, but how can it be determined how much allowance should be made, and how can the work of the two factories be compared directly?

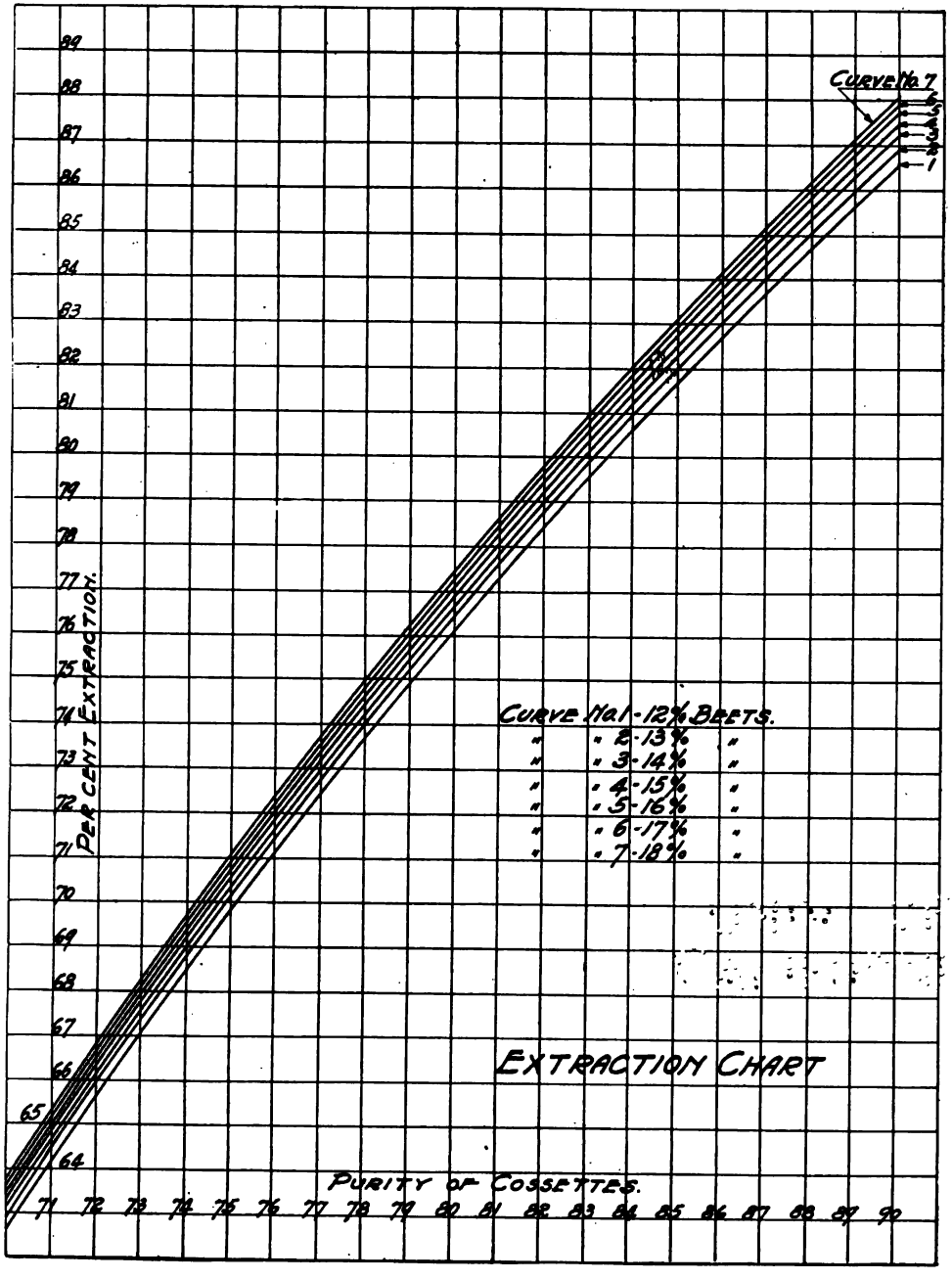
This problem has been solved by first calculating what is termed the "standard extraction" for each factory, which varies with the sugar content and purity of the beets. The standard extraction is based on the following figures:

Beet end elimination	40.0
Total known losses, per cent on beets	.60
Apparent purity of molasses	57.0

These figures, with the two variables, the sugar content and the purity of the beets, give all the necessary data for the calculation of the standard extraction. To shorten the work of computation, the chart on Plate 27 has been prepared which shows at a glance the standard extraction for beets of any purity and percentage of sugar. E. g., in the example above cited, the standard extraction for factory "A" is 81.9, and for factory "B" is 81.0. (Derive these from the chart.)

Having obtained the standard extraction, we then calculate what percentage of the standard extraction the actual extraction is, i. e., we multiply the actual extraction by 100 and divide by the standard extraction. This yields what is called the "performance factor", which can be used to compare factories directly on the basis of their relative efficiency. The performance factors for the two factories in the example are as follows:

Plate No. 27.


Curve No 7
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PER CENT EXTRACTION.
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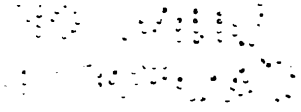
65
64
CURVE No 1-12% BEETS.
" " 2-13% "
" " 3-14% "
" " 4-15% "
" " 5-16% "
" " 6-17% "
" " 7-18% "
EXTRACTION CHART
PURITY OF COSSETTES.
71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90



Factory "A"	Factory "B"
$\frac{79.4 \times 100}{81.9} = 96.9$	$\frac{77.9 \times 100}{81.0} = 96.2$

From this it follows that factory "B", even after allowance has been made for the poorer quality of its beets, has not done as good as factory "A", though the difference is of course less than the difference in the two actual extractions. To equal the performance of factory "A", factory "B" should have obtained an actual extraction of $81.0 \times .969 = 78.5$, instead of 77.9.

To recapitulate, the "standard extraction" is that percentage of the sugar in the beets which can be recovered as granulated with first class technical work in every respect (40 per cent elimination, .60 per cent total losses on beets, and 57.0 molasses purity). The standard extraction is purposely set to represent a very high standard of technical work. Each of the figures on which it is based has, however, been reached, though never all at one time for an entire campaign. That they may not be unattainable as a whole, on the other hand, is indicated by the fact that one factory of this company has succeeded in obtaining a performance factor of 99.5 for a whole campaign.

The "performance factor" represents that percentage of the standard extraction which has actually been obtained, and is a measure of the relative operating efficiency of different factories.

EXTRACTION AND PERFORMANCE AT STEFFEN FACTORIES

In calculating the extraction at a Steffen factory, the following additional points have to be taken into consideration:

(1) The amount of sugar in the Steffen waste water is listed among the "known losses".

(2) The "molasses loss" is calculated by subtracting the amount of sugar in the "molasses worked" from the amount of sugar in the "net molasses produced". If the amount of sugar in the molasses worked exceeds the amount of sugar in the net molasses produced, there is no molasses loss, and the difference, which represents additional sugar introduced into the factory, must be added to the sugar in the cossettes at the top of the statement.

The calculation of the performance factor for a Steffen factory is also a more involved matter, because the extraction depends not only on the quality of the beets and the molasses worked, but also on the relative amount of these two raw materials.

To obtain a standard extraction, it is necessary then first to calculate the standard extraction separately for the beets and the molasses worked. The standard extraction from the beets alone is derived in the same manner as has been described for a non-Steffen factory. The standard extraction from the molasses worked, i. e., the standard "Steffen extraction" is calculated as follows:

The Steffen extraction depends solely on three factors:

(1) The amount of sugar lost, including both the loss in the Steffen waste water and the loss in handling the Steffen material after it is introduced in the main factory.

(2) The purity of the Saccharate Cake.

(3) The purity of the final molasses produced.

As the apparent purity of Steffen products is misleading on account of the large amount of "raffinose" present, it is necessary to employ the true purity in this calculation.

For the losses and the molasses purity a definite figure may be set in each case. The saccharate purity, however, as has been explained before, varies with the quality of the molasses, and accordingly, in setting a standard for this purity, the true purity of the "perfectly washed cake" is used, as this represents the maximum purity attainable with perfect washing.

The standard Steffen extraction is then based on the following figures:

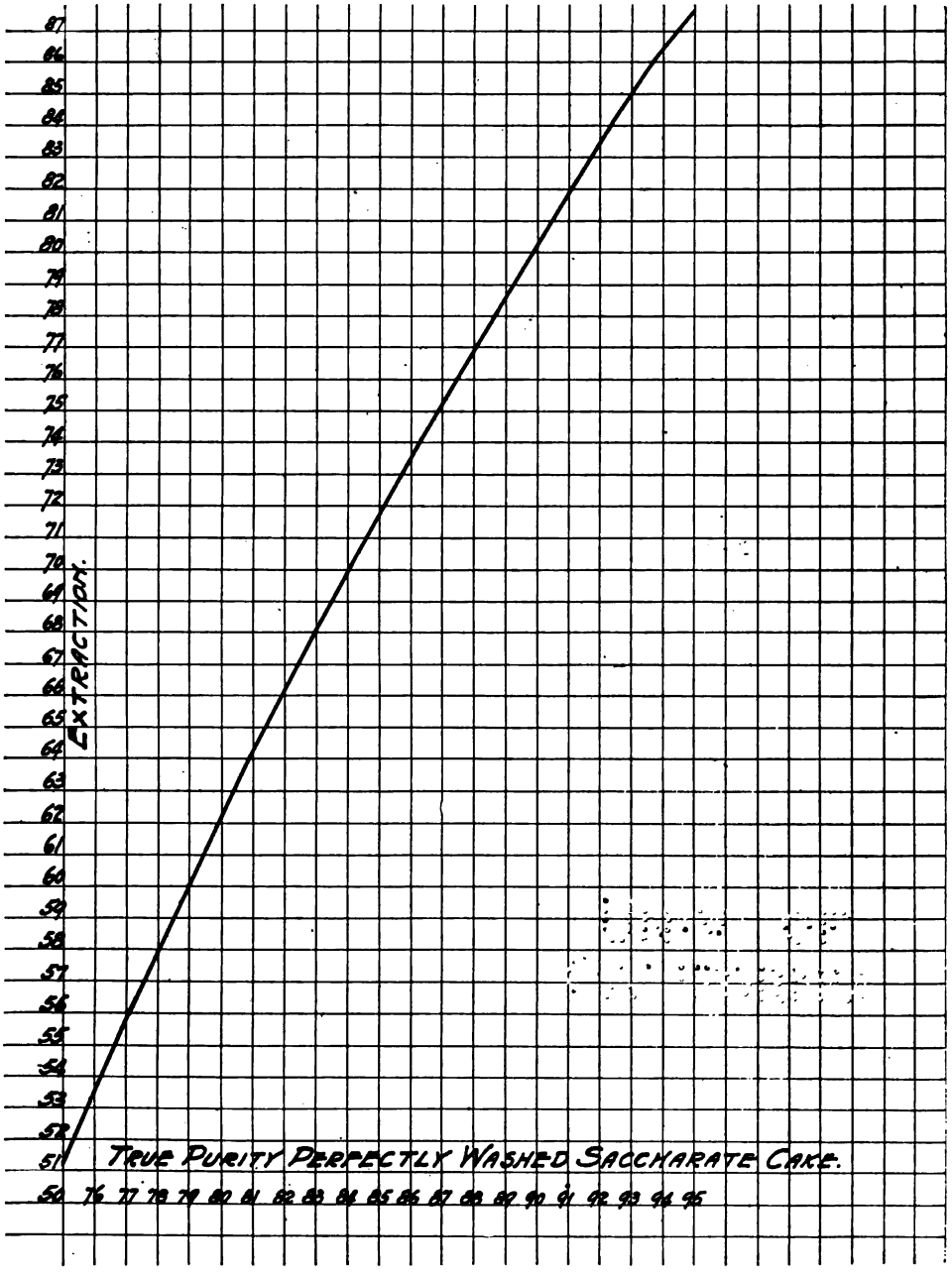
(1) Total loss of sugar = 5.25 per cent of the sugar in the molasses worked, of which 3.00 per cent is allowed for the loss in the Steffen waste water and 2.25 per cent for the loss in the main house.

(2) True purity of molasses produced = 58.0. This does not mean that *all* the molasses produced at a Steffen factory must be of this purity, but refers only to the theoretical portion which is due to the impurities introduced in the saccharate.

The chart on Plate 28 shows the standard Steffen extraction for varying purity of the perfectly washed cake.

When the standard beet and Steffen extraction have been obtained, the performance factor is calculated as follows: Multiply the pounds of sugar in the cossettes by the Standard Beet Extraction, which will give the standard production of granulated from beets. Similarly multiply the pounds of true sugar (sugar by inversion) in the molasses worked by the Standard Steffen Extraction, which will give the standard production of granulated from the Steffen Process. The sum of these two amounts represents the

Plate No. 28.


EXTRACTION.
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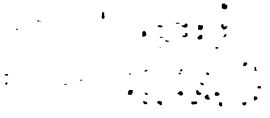
TRUE PURITY PERFECTLY WASHED SACCHARATE CAKE.
76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95



total number of pounds of granulated which would have been produced under standard conditions, and, when divided into the pounds of sugar representing the actual extraction, gives the performance factor.

Example

A factory slices 100,000 tons of beets of 16.0 per cent sugar and 83.2 purity, and works 8,000 tons of molasses containing 53.0 per cent true sugar, the true purity of the saccharate cake being 86.2. The total production of granulated is 315,040 bags.

Pounds of sugar in cossettes = 100,000 × .16 × 2000 = 32,000,000
Standard beet extraction (from chart) ..... = 80.8
Standard beet extraction in
pounds = 32,000,000 × .808 = 25,856,000
Pounds of sugar in molasses
worked = 8,000 × .53 × 2000 = 8,480,000
Standard Steffen extraction (from chart) ..... = 73.8
Standard Steffen extraction in
pounds = 8,480,000 × .738 = 6,258,240
Standard total extraction in
pounds = 25,856,000 + 6,258,240 = 32,114,240
Performance factor = 31,504,000 × 100 ÷ 32,114,240 = 98.1

It can be seen from the above example that a variation of one point in the beet extraction will effect the performance factor more than a variation of one point in the Steffen extraction, because the amount of sugar from beets is always considerably greater than that from the molasses worked. It is easily possible, however, for the Steffen work to be so poor as to spoil the performance factor of a factory which obtains a good beet extraction.

It has been the aim to set the standards for the Steffen extraction just as rigorously, and no more or less so, than those adopted for the beet extraction, in order that Steffen factories may be compared not only with one another, but also with non-Steffen factories, by the use of the performance factor.

EXTRACTION ON BEETS PURCHASED

As this course of lectures is intended primarily for the operating man, whose responsibility first begins with the introduction of the beets into the factory, the subject of extraction has so far been considered only in relation to the weight and quality of the beets as sliced. It must not be forgotten, however, that, on account of the loss in weight which has taken place between the time of delivery and of slicing, the extraction obtained from a ton of beets as "paid for" is always much lower than from a ton of beets "as sliced."

PROBLEMS

(1) A non-Steffen factory slices 86,273 tons of beets containing 15.45 per cent sugar, and produces 204,800 bags of sugar. What is the extraction? How many additional bags of sugar would have been made if the extraction had been half a point higher?

(2) Calculate an extraction statement, according to the form on page 247, from the following data:

Tons of beets sliced	95,050
% sugar in cossettes	16.40
Purity of cossettes	85.6
Bags of granulated produced	254,200
Pounds of sugar in pulp	342,120
Pounds of sugar in pulp water	171,300
Pounds of sugar lost in lime cake	266,480
Pounds of sugar lost in filter cloth washing	21,500
Pounds of sugar in molasses produced	4,080,560

In making up the statement, first fill in all figures in the "pounds" columns and then calculate the percentages, carrying two decimal places. Note that the figures in the percentage columns, obtained by division, must check by addition or subtraction within one unit in the last decimal place. Finally calculate the standard extraction and the performance factor.

Assuming that the Extraction Statement just calculated represents the work of factory "C", and the example given on page 255 the work of factory "A", compare the work of the two factories in the following respects:

Which factory has the higher extraction? Which factory has done the better technical work? How many additional bags of granulated would the poorer factory have had to make to equal the performance of the better factory? How many additional bags of granulated would factory "C" have made if its unaccountable loss had been 20 per cent lower, and what would have been its performance factor? Wherein, as far as appears in the Extraction Statement, has factory "A" done better work than factory "C", and vice versa?

(3) A factory slices beets averaging 15.00 per cent sugar and 84.5 purity. The losses in pulp, pulp water, lime cake, and filter cloth washing amount to a total of .43 per cent on beets, and the molasses loss is 2.28 per cent on beets. To what percentage on beets must the unaccountable loss be reduced in order that the factory may reach a performance factor of 98?

(4) Which influences the performance factor more, a variation of one per cent sugar in the beets or of one point in purity?

CHAPTER NO. XIII

THE BOILER HOUSE

SECTION A

The function of the boiler house equipment is to produce the steam required for power and heating purposes in the factory The steam is produced by the evaporation of water in the boilers, the heat required for evaporation being supplied by the burning of coal, fuel oil, natural gas or other fuel, under the boilers. The fuel used at all the factories of the Great Western Sugar Company is coal, with the exception of the Lovell factory, where natural gas is used.

DESCRIPTION OF THE BOILER HOUSE EQUIPMENT

The boiler house equipment consists of the (1) Boilers proper, including furnaces and mechanical stokers, (2) Boiler breeching and stack, (3) Boiler feed equipment, including boiler feed tanks pumps and lines, (4) Coal handling machinery, (5) Ash and coal drippage handling equipment and (6) The steam piping, valves and fittings.

The following description pertains to the Great Western Sugar Company's campaign equipment. In addition to this campaign equipment some of our factories are supplied with a smaller boiler for intercampaign use.

Boilers.—Both Babcock & Wilcox and Stirling boilers are used at the various factories besides which there is one installation of seven Erie City boilers at Greeley.

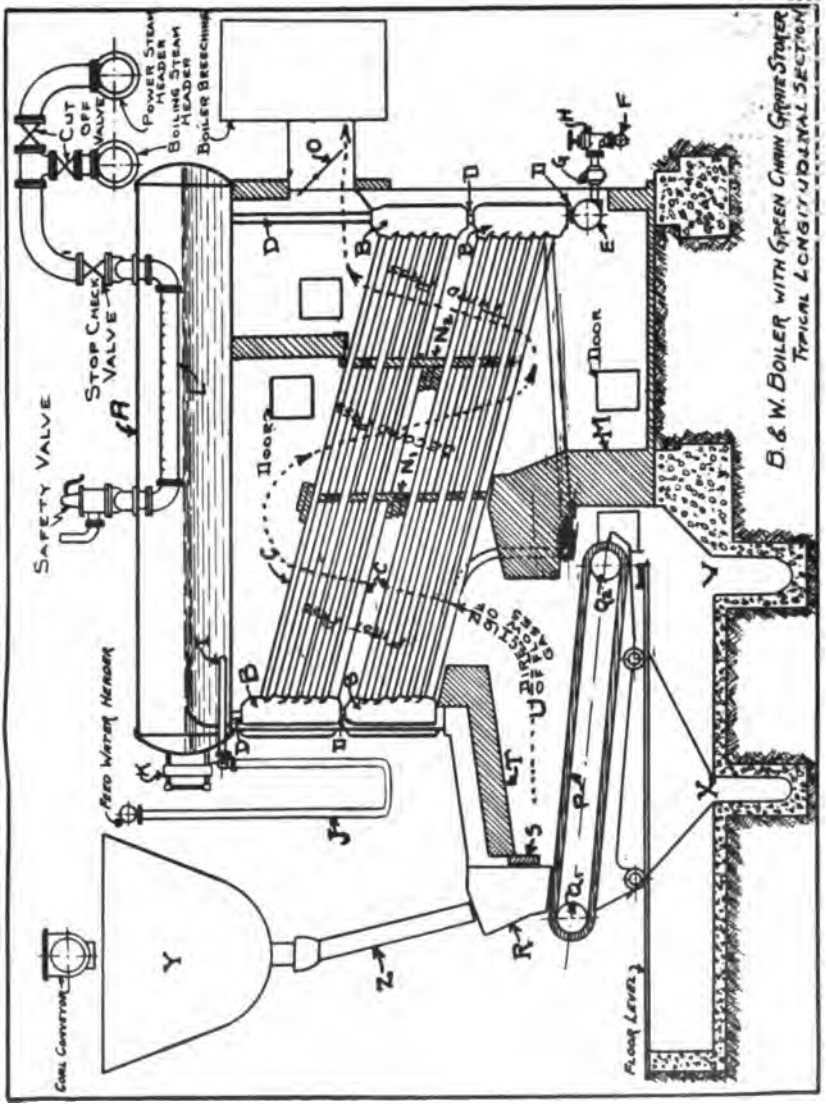
The 350-H. P. B. & W. boiler is shown in diagrammatic section on Plate No. 29. The steam and water are contained in two longitudinal horizontal steel drums "A", each 42 inches diameter and about 20 feet long, and in 168 inclined steel tubes "C", each 4 inches diameter and 18 feet long. The 168 tubes are arranged in twelve layers, each layer fourteen tubes wide, and the tubes are at both ends connected to vertical cast iron or steel headers "B" of a rectangular cross section, six tubes being connected to each header. The headers are of a sinuous form, causing the tubes in each two adjoining layers to be staggered, which arrangement gives a better exposure of the tubes to the flow of the combustion gases than if

the tubes were placed vertically above one another. The lower and upper headers are connected together and the upper headers are in turn connected to the drums "A", all these connections being made with 4-inch nipples "D". The mud drum "E" is connected to each of the fourteen lower rear headers by 4-inch nipples "D". The mud drum is also connected to the blow-off line "F", a stop cock "G", and a blow-off valve "H" being placed in this connection. The stop cock "G" is to be left open and only to be closed when it becomes necessary to repair the blow-off valve "H". The feed water is supplied to the boilers through the pipe "I", passing through the front head of both of the drums "A" close to the bottom. The pipe "I" is connected to the feed water header by a loop formed pipe "J". The water tenders regulate the feed water supply by adjusting the valves in this loop pipe. The water level is observed by means of the gauge glass on the water column "K" and should, during operation, always be kept as close to the center line of drum "A" as possible. The water column is equipped with a device which causes a whistle to blow whenever the water level gets below or above the proper working limits. Each boiler is equipped with a pressure gauge which indicates the steam pressure in the boiler.

The upper part of drums "A" acts as a steam reservoir from which the steam is taken from the boiler through the dry pipe "L", one end of which is connected to the steam outlet from the boiler and the other end to the safety valve. The dry pipe is perforated on the upper side, the total area of the perforations being larger than the steam outlet from the drum. The steam outlets of the two drums are connected with a cross pipe and this is in turn connected, through a stop check valve, to the steam headers. The purpose of the stop check valve is to prevent the steam from all the boilers in the system escaping in case one of the boilers explodes or a tube blows out. The boiler and furnace are enclosed in a casing of brickwork called the "Boiler Setting." The boiler setting in connection with the bridge wall "M" and the front and rear baffles N_1 and N_2 forms the first, second and third passes for the combustion gases. The third pass is connected to the breeching by a short flue of sheet steel in which the damper "O" is placed.

The B. & W. and Stirling boilers in use at most of the factories of the Great Western Sugar Company are equipped with either Green or Babcock & Wilcox automatic chain grate *stokers*. The grate consists of an endless belt "P", 7 or 8 feet wide, made up of cast iron links and traveling around sprockets Q_1 and Q_2, the driving mechanism being at the front end of the stoker. The

Plate No. 29


B. & W. BOILER WITH GREEN CHAIN GRATE STOKER
TYPICAL LONGITUDINAL SECTION
SAFETY VALVE
STOP CHECK VALVE
CUT OFF VALVE
POWER STEAM HEADER
BOILING STEAM HEADER
BOILER BREECHING
FEED WATER HEADER
DOOR
DOOR
DOOR
FLOOR LEVEL
GRATE SURFACE
ASH PIT

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coal is fed to the traveling grate by the feed hopper "R", which is equipped with an adjustable gate "S", the position of which determines the thickness of the fuel on the grate. The stoker is driven at a variable speed by an adjustable ratchet and pawl arrangement from a line shaft which in turn is driven by a small steam engine. The power required to drive one stoker is about one horse power. Over the stoker grate is suspended the ignition arch "T", the stored up heat of which ignites the coal by radiation as the fuel enters the combustion chamber "U". A space of about 3 inches is left between the rear end of the grate and the water back "W" under the bridge wall. Through this opening the ashes drop from the rear end of the chain grate into the ash flume "V" and fine coal falling unburned through the grates is collected in the coal drippage flume "X". In both of these flumes there is running a swift current of water which carries the ashes and coal to the ash pump and coal drippage pump respectively, from which the ashes are discharged through a pipe line to the ash pit and the coal drippage to the coal drippage pit.

A 350-H. P. Stirling boiler is shown in diagrammatic section on Plate No. 30. The steam and water are contained in three upper cross drums 42 inches diameter, one lower cross drum 48 inches diameter (all drums about 12 feet long) and in 270 3¼-inch tubes varying in length from about 12 to 18 feet. The principal parts of this boiler will be readily recognized by referring to the description of the B. & W. boiler and at the same time studying Plate No. 30.

Plate No. 31 shows a section through a 350-H. P. Erie boiler equipped with hand fired furnace. The construction of this boiler is somewhat similar to the B. & W. boiler as it has two longitudinal drums each 36 inches diameter by about 22 feet long, and 160 4-inch tubes 18 feet long, the tubes being connected to the drums by waterlegs. The baffles are horizontal in this boiler.

Heating Surface of Boilers.—The tubes and that part of the drums which is exposed to the combustion gases is called the heating surface of the boiler. The heating surface in a 350-H. P. B. & W. boiler is 3,467 sq. ft.; for a 350-H. P. Sterling boiler, 3,544 sq. ft., and for a 350-H. P. Erie boiler, 3,345 sq. ft., or about 10 sq. ft. per rated horse power.

Grate Surface.—That part of the stoker grate which forms the bottom of the combustion chamber and on which the burning of

the coal takes place is called the grate surface. The grate surface of a mechanical stoker, as used in the Great Western Sugar Company's factories, is for a 350-H. P. boiler 80 sq. ft., and for a 266-H. P. boiler 67 sq. ft.

Breeching and Stack.—The boiler breeching carries the combustion gases to the stack, which furnishes the necessary power to pull the air and combustion gases through the boiler and breeching, as explained below under "draft". The breeching is usually of steel and should have a cross section area equal to or greater than that of the damper areas of all the boilers served. Most of the Great Western Sugar Company's stacks now in use are built of reinforced concrete, only one stack being of steel and one of brick. The reinforced concrete stack at Brighton is 11′ 0″ inside diameter at the top and 252 feet high, and the stack at Longmont is 12′ 6″ inside diameter at the top and 251 feet above the boiler house floor. These stacks are examples of stacks in use at a small and at a large factory.

Boiler Feed Tanks, Pumps and Lines.—The feed water is drawn from the boiler feed tank, which may be located either in the boiler house or in the main building, and forced through the boiler feed line to the boilers by pumps, which are usually of the direct steam driven piston type, though a few centrifugal pumps are used. Some factories are also equipped with independent pumps for returning the condensed water from the pans direct to the boilers. A relief valve should be provided in the discharge line of all boiler feed pumps to relieve the discharge pressure in case the feed valves of all the boilers are closed. All boiler feed line fittings should be extra heavy.

Coal Handling Machinery.—The coal is dropped from railroad cars in the track hopper outside the boiler house and carried by a conveyor, generally of the steel apron type, to the crusher, where it is reduced to a size of about 1¼″ cube or smaller, if the crusher is working properly. The crusher consists at most factories of a pair of cast iron rolls, the surface of which is provided with teeth about 2¼″ long and spaced about 3″ center to center. From the rolls the coal is elevated by a bucket elevator and distributed by a conveyor (usually a scroll) in the overhead storage bin "Y" (see Plate No. 29), from which the coal in drawn through the spout "Z" to the stoker feed hopper "R".

Plate No. 30.

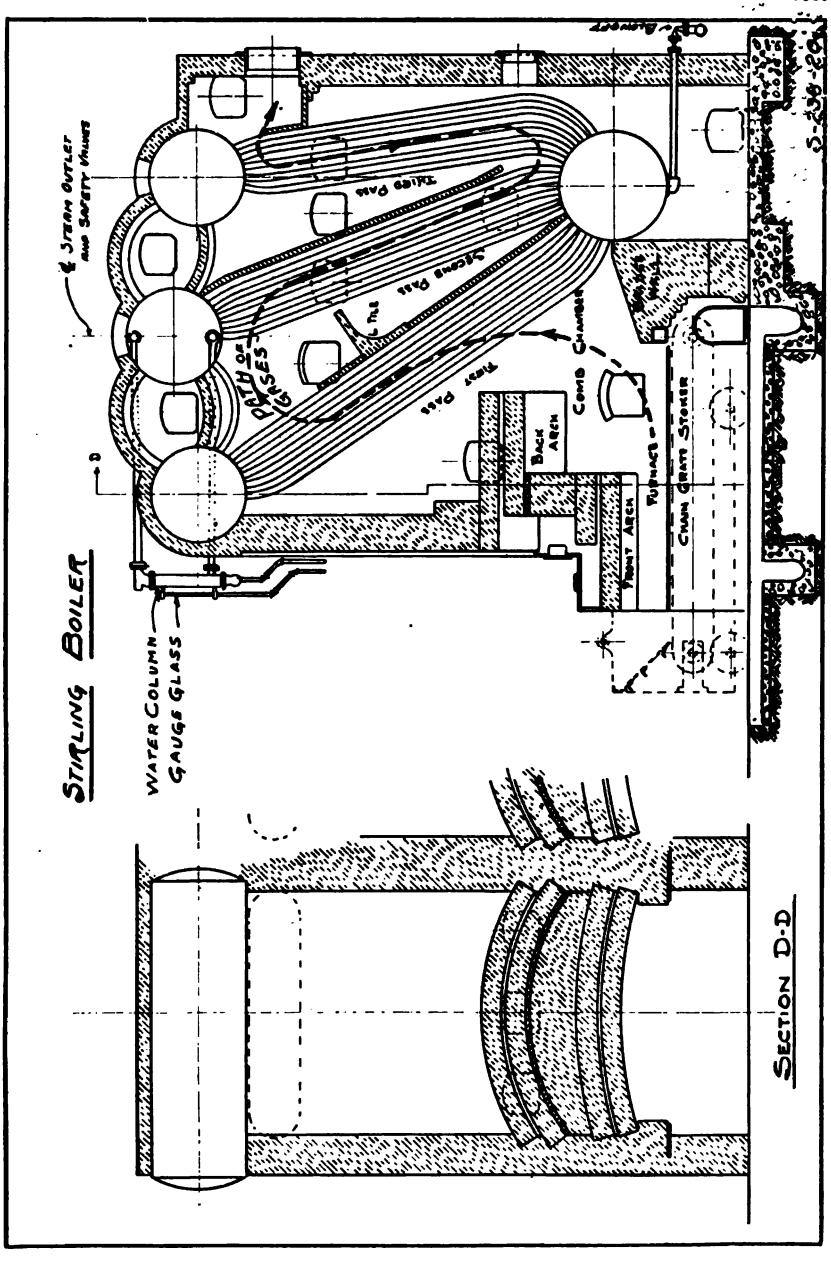
STIRLING BOILER
WATER COLUMN
GAUGE GLASS
STEAM OUTLET AND SAFETY VALVES
PATH OF GASES
TRIPLE PLATE
SECOND PLATE
FIRST PLATE
COMB CHAMBER
BACK ARCH
FRONT ARCH
FURNACE
CHAIN GRATE STOKER
SECTION D-D

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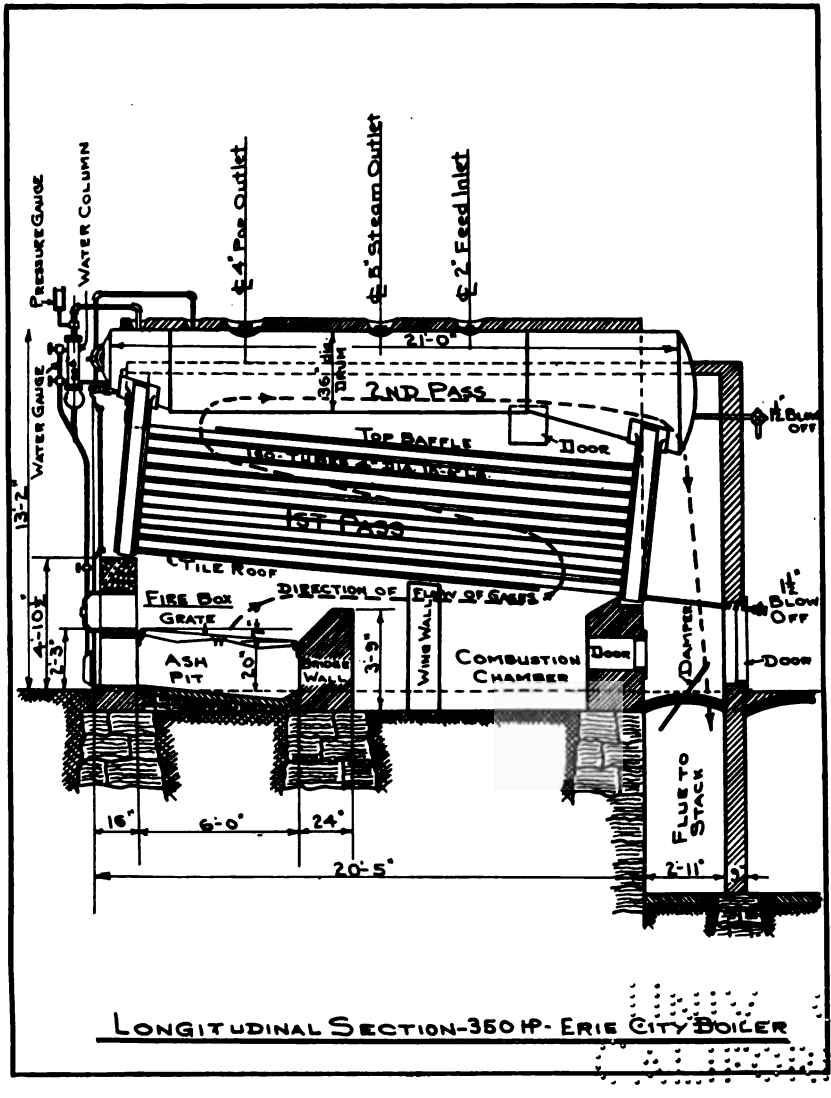
Plate No. 31.



LONGITUDINAL SECTION-350 HP- ERIE CITY BOILER

Plate No. 32.

DIAGRAM SHOWING INFLUENCE OF BAFFLES ON HEAT ABSORPTION

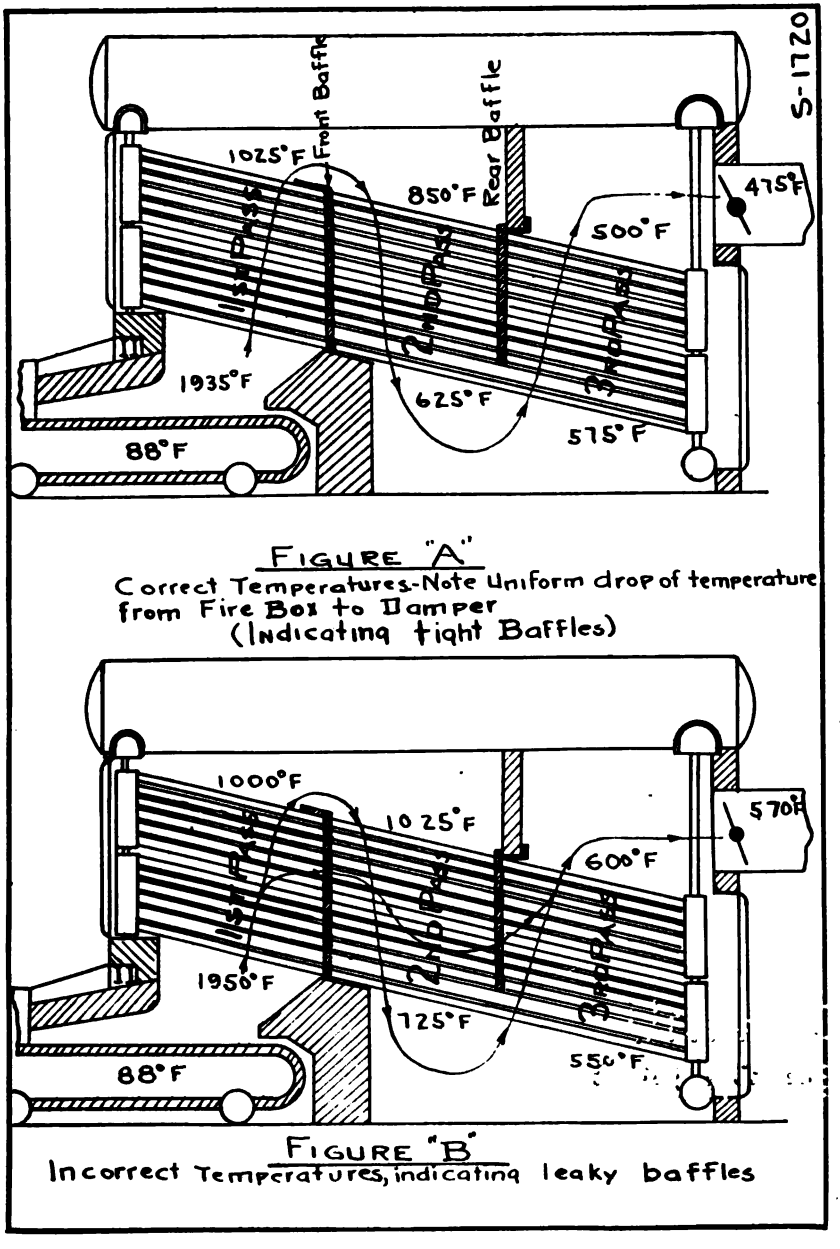


FIGURE "A"

Correct Temperatures-Note Uniform drop of temperature from Fire Box to Damper (Indicating tight Baffles)

FIGURE "B"

Incorrect Temperatures, indicating leaky baffles

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Ash and Coal Drippage Handling Equipments.—The ash discharged from the stokers is flushed by water through the ash flume to the ash pump The ash pumps used are 6″ manganese steel lined centrifugal pumps, which force the mixture of ashes and water through a pipe line to a settling pond.

The coal drippage is handled in a similar manner through the drippage flume to a 3″ manganese steel lined centrifugal pump which sends the drippage either to a special settling pit or to the regular coal storage pit. The drippage is in either case returned to the stokers and burned. At Billings the drippage system consists of a system of scroll conveyors which convey the drippage to a bin from which it is taken and mixed with the regular coal supply.

Steam Piping Valves and Fittings.—All the live steam valves and fittings in the boiler house as well as in the factory should be extra heavy and all live steam piping should be wrought steel with lap welded seams.

Each boiler should be equipped with a pop safety valve, a stop check valve and a cut off valve.

OPERATION OF THE BOILER HOUSE

Stokers.—It is important that the coal is crushed to as uniform a size as possible, 1¼″ cube or smaller, in order to obtain an economical combustion. If larger lumps of coal are fed to the stokers, such lumps may be carried to the ask flume only partly burned and thus cause excessive ash loss. If the coal fed to the stokers contains a considerable amount of fine particles, as most coal does, and is dry, it should be moistened sufficiently before entering the stoker to make the dust and finer particles stick together or to the larger pieces of coal, as a better efficiency may be obtained by this procedure on account of the fuel bed giving a more uniform resistance to the passage of air and thus burning more evenly.

The best boiler efficiency obtained with the coal usually used in our factories is obtained when stokers are operating under the following conditions:

Thickness of coal on grate.....5″ to 6″
CO_2.....11½% to 13%
Furnace Draft.....25″ to .35″
Flue gas temperature.....450° F. to 500° F.

Ash in ash.....70% to 90%
Line Shaft.....About 45 R. P. M.
Ratchet feed.....About 3 notches

These conditions of course must be varied with varying steam requirements and with varying qualities of coal.

For instance, with a very fine coal it might be necessary to increase the draft or decrease the thickness of the fire and speed up the grate. The thickness of the fire, the draft and the speed of the grate can be changed by the fireman at will, and he must learn the proper combination of these conditions which will give the highest per cent CO_2 and highest per cent ash in ash at the same time, holding the steam at the proper operating pressure.

Low CO_2 is caused by short fires, holes in the fire, excessive draft with thin fires or by leaks in the boiler setting.

High flue gas temperature is caused by dirty tubes, by leaky baffles which allow part of the hot gases to be short circuited, or by incomplete combustion of the gases in the combustion chamber. The last mentioned cause is often indicated by a high CO_2 per cent.

Low ash in ash, which means considerable coal left unburned in the ash, is caused by too thick fires, by insufficient draft, by too high a grate speed, or by some combination of the above conditions, or by large lumps of coal which do not have time to burn completely while traveling the length of the grate.

Flue Blowing.—It is very important that the heating surfaces of the boilers are kept free from soot and clinkers in order to get a good heat transmission from the flue gases through the metal to the water. A thin layer of soot on the tubes will cause high flue gas temperature and thus high flue gas losses. The flue gas temperature should be between 425 and 525° F. and ordinarily not much above 500° F. All flues should be blown at least once every twelve hours and preferably once every eight hours. The blowing is done with live steam through a pipe nozzle, sometimes telescoping, and long enough to reach all the tubes.

Baffles.—The baffles separating the different passes should always be kept tight in order to prevent short circuit of the combustion gases through the boiler. Leaky baffles tend to cause high flue gas temperatures. Fig. A, Plate No. 32, shows the temperature in degrees Fahrenheit which should exist in different passes of a

properly operated B. & W. Boiler when the baffles are tight. Figure B, Plate No. 32, shows temperatures which indicate that the baffles are in a poor condition.

Feed Water.—The boiler feed water is supplied by the drip water from the 2nd, 3rd and 4th bodies of the evaporators and from the pan coils, all live steam traps, battery calorizators, drip from vapor pans, and by such other condensed hot water that is not likely to contain any sugar or oil. The drip water is all collected in the boiler feed tank. The drip water from the 1st body is not used because it contains oil from the exhaust steam, the introduction of which in the boilers would be injurious to them.

It is very important to guard against sugar getting into the feed water, as the sugar will decompose at the high temperature and form acid which in time may cause dangerous corrosion of the boilers. As traces of sugar do get into the boiler feed water at times, the water in the boilers is kept alkaline by the addition of soda. The alkalinity should be carried at .02 or higher but not high enough to cause foaming.

Steam Pressure.—The boilers are ordinarily operated in a high pressure and a low pressure group. The high pressure boilers supply steam to the power header and the low pressure boilers to the boiling header. The high pressure group should produce more steam than is used by the engines in the factory through the power header, the excess high pressure steam being blown into the boiling header through a cross connection in which a Locke pressure regulating valve is installed. This valve should be so connected and adjusted that when the steam pressure in the power line reaches a certain point the Locke valve automatically opens and allows the steam to flow over into the boiling header. This arrangement allows a uniform steam pressure to be maintained in the power header supplying the steam engines, and also allows the boilers connected to the power header to be operated at a uniform and efficient rating.

The variation in steam consumption is ordinarily taken care of in the operation of the boilers connected to the boiling header, and it is therefore generally not possible to operate the low pressure boilers at as high an efficiency as the high pressure boilers. The greatest variation in steam consumption is caused by the pans, the maximum consumption occurring while the pan is graining.

If the high pressure boilers carry 130 pounds working pressure then the low pressure or boiling steam should be kept between 110 and 120 pounds. The safety valve should be set not more than five pounds higher than the working pressure. The boiler pressure should be raised high enough once every twenty-four hours to let the *safety valves* operate to insure against the valve discs sticking to the seat.

The *stoker water backs* should be blown off once every twenty-four hours.

The boiler blow-off valves should be opened at least once every twenty four hours to blow from the mud drums any sediment collected in them. The water column should be blown down at least once on each shift and checked against the test cocks.

Low Water.—Water must, under no condition, be added to a boiler in operation if the water level should go below the water gauge or lower sample cock on the water column. The fire must, in such case, be put out immediatel yand the boiler cut out of line. The boiler must not be put in operation again before a thorough examination has been made to make sure that none of the water containing parts have suffered any damage by being exposed to the hot gases without being covered with water on the inside.

SECTION B

COMBUSTION

In boiler room practice combustion is understood to be the burning of the different kinds of fuels used, such as coal, oil, gases, and wood. The combustion of a fuel involves the rapid chemical union of oxygen with certain of the elements and compounds of which the fuel is composed. These elements and compounds are called combustibles. The oxygen required for combustion is supplied to the boiler furnace from the air, which is a mechanical mixture of about 21 per cent oxygen and about 79 per cent nitrogen measured by volume. The proportion of oxygen and nitrogen in the air by weight is oxygen 23.15 per cent, and nitrogen 76.85 percent.

Oxygen is a colorless and odorless gas occurring in a free state in the air but mixed with nitrogen as stated above. The presence of oxygen is absolutely necessary wherever combustion is going on.

Nitrogen performs no useful office in combustion and passes through the furnace without change. It dilutes the air, absorbs heat, reduces the temperature of the products of combustion and is the chief source of heat losses in furnaces, on account of the heat it carries off to the stack.

The principal combustibles in coal are carbon, hydrogen and sulphur.

Carbon is the most abundant, as it, for all coal, amounts to more than 50 per cent of the total weight. Carbon in its pure state is a solid such as graphite and diamond. In coal part of it is pure and part in combination with hydrogen forms hydro-carbons. The pure carbon in coal is referred to as "fixed carbon" because when the coal is heated the hydro-carbon vaporizes and passes off in the air, while the pure carbon remains.

Hydrogen is a colorless and odorless gas and may occur in a free state in small quantities in some fuels, but is usually found in combination with carbon as hydro-carbons, which forms the principal part of the volatile matter in coal. Liquid fuels, such as oil, gasoline, etc., consist mainly of hydro-carbons. Fuel gases contain hydrogen both in the free and the combined state. As examples of hydro-carbons may be mentioned the two gases, methane CH_4 and acetylene C_2H_2.

Sulphur in its pure state is a yellow solid substance. It exists in practically all coals. It is undesirable in fuel because its combustion products with moisture form acid, which corrodes the iron work of flues. The amount of sulphur in coal is small and its heat value is low.

Kindling Point: Before a combustible can unite with oxygen and combustion take place, its temperature must be raised to the ignition or kindling point. The kindling point in degrees Fahrenheit is as follows: lignite dust 300, coal 600, sulphur 470, carbon-monoxide 1,200, hydrogen 1,000 to 1,300.

Combining Weight and Heat Value: Each combustible element will combine with oygen in certain definite proportions called atomic or combining weights and will, during this process, generate a certain amount of heat, which is called the heat value, and is measured in B. T. U. per pound of combustible. One B. T. U. is the amount of heat required to raise the temperature of one pound of water one degree F. (See page 89.)

The combining weight of oxygen is 16 and its chemical symbol is "O." The combining weight, chemical symbols, heat value and other useful combustion data for carbon, hydrogen and sulphur, are given in the following table:

TABLE I

COMBUSTION DATA

1	2	3	4	5	6	7	8
Name of Combustible	Chemical Symbol	Combining Weight	Combustion Formula	Compound Formed	Heat Value per lb. of Combustible B. T. U.	Lbs. of Oxygen required per lb. of combustion	Lbs. of Air required per lb. of combustion
Carbon	C	12	$C + O = CO$	Carbon-Monoxide	4450	1⅓	5.75
Carbon	C	12	$C + 2O = CO_2$	Carbon-Dioxide	14600	2⅔	11.52
Carbon-Monoxide	CO	28	$CO + O = CO_2$	Carbon-Dioxide	4350	4/7	2.47
Hydrogen	H	1	$2H + O = H_2O$	Water	62000	8	34.56
Methane	CH_4	16	$CH_4 + 4O = CO_2 + 2H_2O$	Carbon-Dioxide & Water	23550	4	17.28
Sulphur	S	32	$S + 2O = SO_2$	Sulphur-	4050	1	4.32

It will be seen from this table that a pound of carbon will unite with 2⅔ lbs. of oxygen and form carbon-dioxide (CO_2). During this process 14,600 B. T. U. will develop. The amount of oxygen required per pound of carbon is arrived at as follows:

The chemical formula CO_2 means that 12 weight units of carbon are combined with two times 16 weight units of oxygen, the combining weights of carbon being 12 and of oxygen 16, or 12 lbs. carbon are combined with $2 \times 16 = 32$ lbs. oxygen, or one pound carbon will combine with 2⅔ lbs. oxygen. The amount of air required is found by dividing 2⅔ lbs. by 23.15 (the per cent of oxygen in the air) and multiplying the result by 100, which gives 11.52 lbs. of air required for the combustion of one pound of carbon to carbon dioxide (CO_2).

A pound of carbon may, as an intermediate step, combine with 1⅓ lbs. oxygen to form carbon monoxide, CO, and evolve 4,450 B. T. U., but CO may further be converted to CO_2 by the addition of another 1⅓ lbs. oxygen to the original pound of

carbon, and thus evolve the remaining 10,150 B. T. U. When a pound of CO burns to CO_2, only 4,350 B. T. U. are evolved, since a pound of CO contains only $^3/_7$ pound of carbon, as shown by the following calculations:

12 lbs. carbon + 16 lbs. oxygen = 28 lbs. carbon-monoxide, or

$$1 \text{ lb. CO} = \frac{12}{28} \text{ lbs. C} + \frac{16}{28} \text{ lb. O} = \frac{3}{7} \text{ lb. C} + \frac{4}{7} \text{ lb. O.}$$

1 lb. carbon contained in CO developes by combustion 10,150 B. T. U. or $\frac{3}{7}$ lbs. carbon developes $10{,}150 \times \frac{3}{7} = 4350$ B. T. U.

The formation of CO is called incomplete combustion of carbon, as the CO may be burned to CO_2, while the formation of CO_2 is called complete combustion, because it is not possible to combine chemically more oxygen with CO_2 than already contained in this compound.

The combustion product of hydrogen is water, H_2O.

Analysis of Coal: Two kinds of analyses are applied to coal, the ultimate analysis and the proximate analysis.

The *ultimate analysis* is a complete analysis giving the amount of carbon, hydrogen, oxygen, nitrogen, sulphur, and ash, which the dry coal contains.

The *proximate analysis* gives the amounts of moisture, volatile matter, fixed carbon, and ash contained in the fuel. The following table gives the average ultimate and proximate analysis of northern Colorado lignite coals, such as used in the Colorado factories.

TABLE II

UNITED STATES GOVERNMENT ANALYSIS OF NORTHERN COLORADO LIGNITE COAL

(AVERAGE OF 12 SAMPLES)

PROXIMATE ANALYSIS				ULTIMATE ANALYSIS							
Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Air Drying Loss	Ash	B. T. U.
19.54	31.16	44.38	4.92	.36	6.00	57.05	1.10	30.55	11.5	4.92	9578

The *theoretical amount of air* required to burn one pound of coal, having the ultimate analysis given in the above table, is cal-

culated below. Practically all the oxygen in coal is already combined with a portion of hydrogen in the form of water and as one pound of hydrogen combines with eight pounds of oxygen, then the hydrogen available for combustion will be H — ⅛ O. Table I gives the amount of oxygen required for one pound of each of the combustibles, carbon, hydrogen and sulphur. The theoretical amount of oxygen required for the combustion of one pound of northern Colorado lignite coal is then—

For the Carbon, $\frac{57.05}{100} \times 2\frac{2}{3} = 1.5213$ lbs. oxygen required

For the Hydrogen,

$\frac{6.00 - (\frac{1}{8} \times 30.55)}{100} \times 8 = .1744$ lbs. oxygen required

For the Sulphur, $\frac{.36}{100} \times 1 = .0036$ lbs. oxygen required

Total.....1.6993 lbs. oxygen required

One pound of oxygen is contained in 4.32 lbs. of air. The total air needed for the complete combustion of one pound of this coal, therefore, is $1.6993 \times 4.32 = 7.34$ lbs. In practice it is impossible to obtain perfect combustion with the theoretical amount of air, and an excess amounting to from 40 to 75 per cent is required for the economical combustion of Colorado lignite coal in chain grate stokers. It is, however, important that the amount of excess air is kept as low as possible, if the combustion at the same time is complete, as the more air there is admitted to the furnace, the more the products of combustion will be diluted and will carry off a proportionately increased amount of heat in the flue gases, or the excess air may lower the temperature of the furnace gases so as to delay the combustion to an extent which will cause CO (carbon monoxide) to pass off unburned from the furnace.

The percentage of CO_2 in the flue gases is an indication of the amount of excess air taken through the furnace and is thus an indication of furnace efficiency. The higher the CO_2 percentage, the smaller is the percentage of excess air. (Plate 33.) This is the reason why it is important to keep the CO_2 content for flue gas high. The CO_2 is measured in per cent of flue gas by volume. The curve on Plate 34 shows how the amount of flue gas is increased very fast as soon as the CO_2 content drops below 9 per cent. If a fuel containing no other combustible than carbon is burned completely with the theoretical amount of air, the combustion gas will contain 21 per cent CO_2. A high CO_2 percentage is, however,

Plate No. 33.

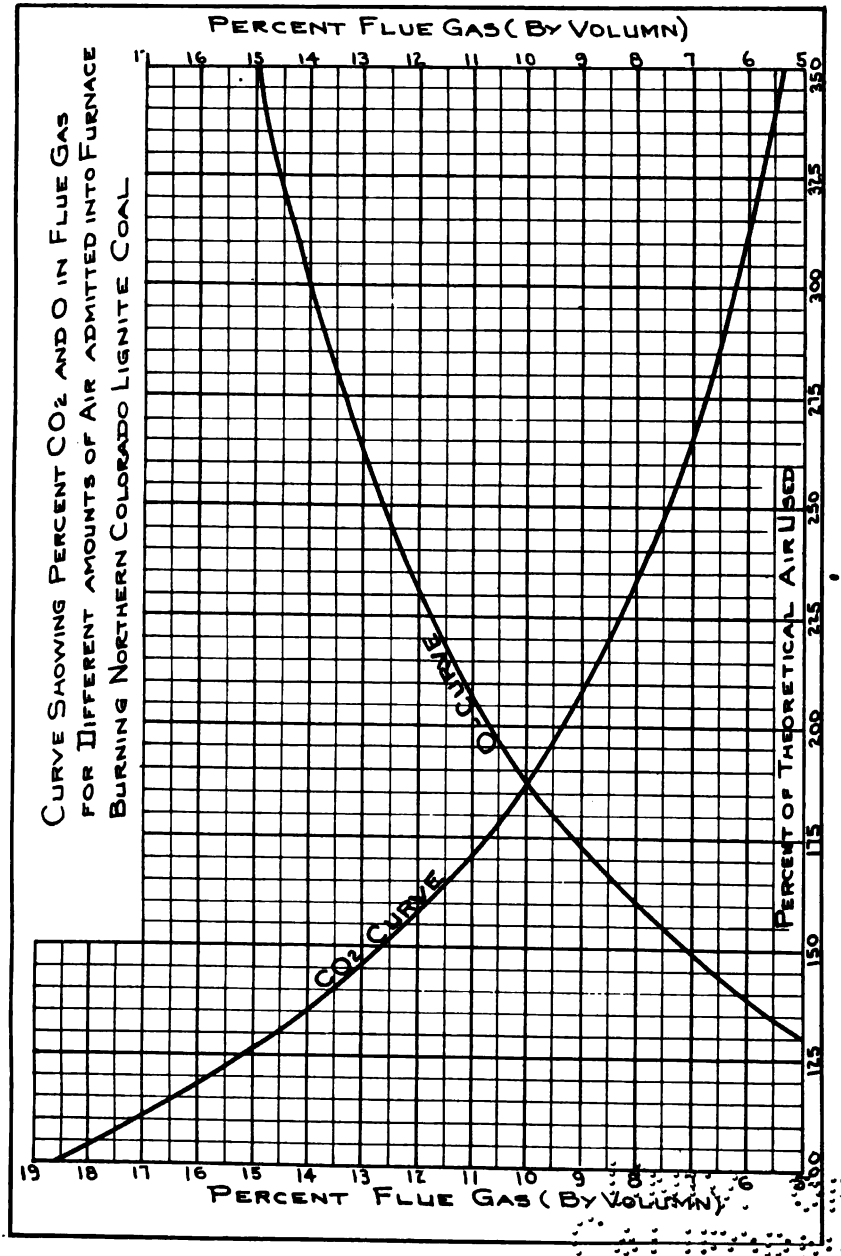
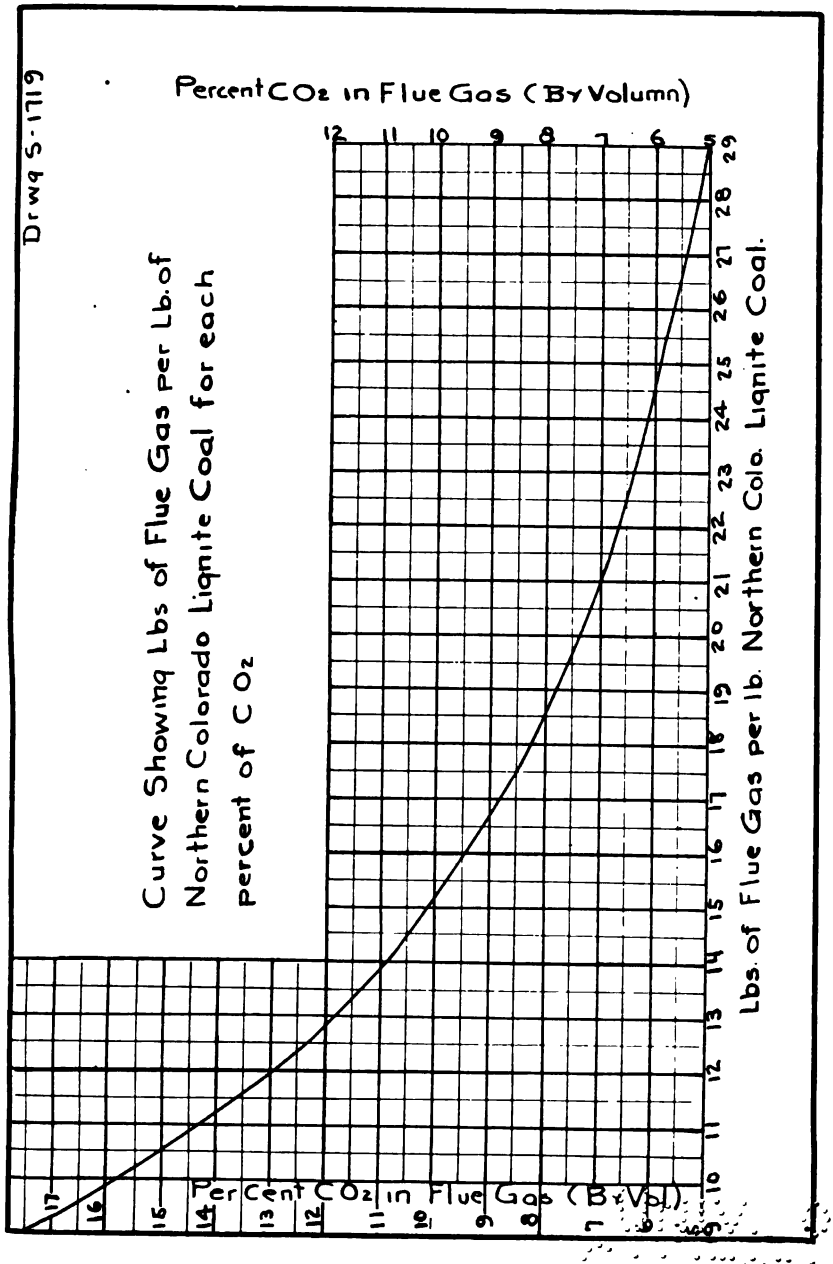

CURVE SHOWING PERCENT CO_2 AND O IN FLUE GAS
FOR DIFFERENT AMOUNTS OF AIR ADMITTED INTO FURNACE
BURNING NORTHERN COLORADO LIGNITE COAL
PERCENT FLUE GAS (BY VOLUMN)
PERCENT FLUE GAS (BY VOLUMN)
PERCENT OF THEORETICAL AIR USED
O CURVE
CO_2 CURVE

Plate No. 34.


Drwg S-1119
Curve Showing Lbs of Flue Gas per Lb. of Northern Colorado Lignite Coal for each percent of CO_2
Percent CO_2 in Flue Gas (By Volumn)
Lbs. of Flue Gas per lb. Northern Colo. Lignite Coal.
Per Cent CO_2 in Flue Gas (By Vol.)

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not always a sign of high furnace efficiency, but must be considered together with the CO content of the flue gases and the loss of unburned coal in the ash.

An analysis with coal firing which indicates 13 per cent of CO_2 and no CO is more favorable from a heat loss standpoint than one that gives 15 per cent CO_2 and one-half per cent CO. As the carrying of a high percentage of CO_2 is apt to lead to secondary combustion between the boiler tubes, thereby involving an additional loss through increasing the temperature of the flue gases, it can readily be seen that it is often a mistake to aim for too high a percentage of CO_2. How high a percentage should be aimed at depends upon the form of furnace and the furnace volume. With the furnace volume of the Great Western Sugar Company's installations, it does not pay ordinarily to go much above 13 per cent. The larger the volume of the furnace, the higher the CO_2 percentage which may be carried.

EVAPORATION

The principles of evaporation are explained in Chapter No. 6, as applied to the evaporators, but the same principles are easily applied to the boiler, the boiler in fact being a single effect evaporator in which heat contained in the combustion gases is transmitted through the heating surfaces and utilized for the evaporation of water. Without further elaboration on the discussion of the theory and principle of evaporation, the meaning of the expression "Boiler Horse Power" will be explained here.

A *boiler horse power* is a measurement of evaporation and is defined as the evaporation of 34.5 lbs. of water per hour from and at 212° F. or its equivalent, requiring $970.4 \times 34.5 = 33{,}478.8$ B. T. U. As it is not possible to apply this measurement of capacity to a boiler except when it is in operation, it is generally adopted that a boiler should have 10 sq. ft. of heating surface for each horse power of its "rated horse power", (explained before under "Heating Surface").

The horse power, as applied to motive power, is equivalent to 33,000 foot pounds per minute, which means that the engine or motor is able to produce a power which will lift 33,000 pounds to a height of one foot in one minute, or move a body against a resistance of 33,000 pounds a distance of one foot in one minute. The amount of steam used per horse power in an engine varies within very wide limits according to the kind and size of engine, the steam pressure, the back pressure and the ratio of expansion in

the steam cylinder. For a large, high pressure, condensing steam engine the steam consumption may be below ten pounds of steam per horse power per hour, while the steam consumption for low pressure engines with high back pressure may be several hundred per cent more. The average steam consumption of the main engines of the Great Western Sugar Company is probably at least 26 pounds per horse power hour.

The smaller steam units, such as direct connected steam pumps, use considerably more steam.

BOILER EFFICIENCY

By boiler efficiency is understood in every day operation the combined efficiency of the stoker and the boiler proper. Boiler efficiency is the ratio of the heat absorbed by the water to the total available heat supplied to the furnace, the latter item being based on the number of pounds of fuel fired and the heat value of the fuel when fired.

The difference between the total available heat supplied to the furnace and the heat contained in the water and steam is called the *"boiler loss."*

The boiler loss is made up of the following items:

1. Loss due to heat carried away by dry flue gases (low CO_2 and high flue gas temperatures).

2. Loss due to moisture in the coal and moisture formed by combustion of hydrogen.

3. Loss due to unburned coal in the ashes.

4. Loss due to incomplete combustion—CO.

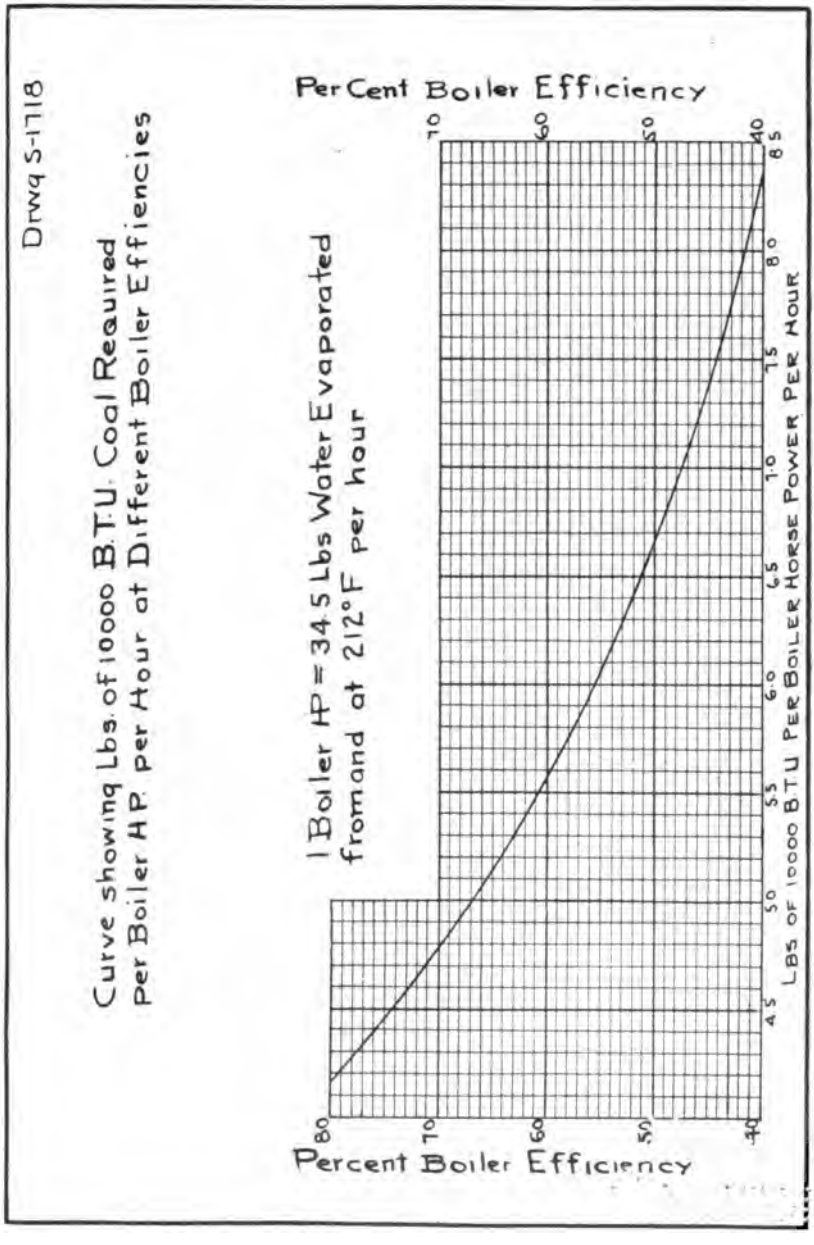
5. Unaccountable losses, such as due to radiation from the boiler setting and to unburned particles of coal being carried beyond the bridge wall.

Losses 1, 2, 3 and 4 are to some extent controllable and dependent upon the skill of the fireman. Methods for figuring losses 1, 2 and 3 are given below under *"Boiler House Control."*

Loss 4 is not considered in daily operation, as it is insignificant under ordinary operating conditions in the Great Western Sugar Company's factories, if the CO_2 per cent does not exceed 13 per cent. If the flue gases contain more than 13 per cent CO_2, samples should be analyzed for CO.

Loss 5 is outside the fireman's control, except that it is increased when excessive draft is used. This loss amounts to from

Plate No. 35.


Drwg S-1718
Curve showing Lbs. of 10000 B.T.U. Coal Required per Boiler HP per Hour at Different Boiler Effiencies
1 Boiler HP = 34.5 Lbs Water Evaporated from and at 212°F per hour
Per Cent Boiler Efficiency
Percent Boiler Efficiency
Lbs of 10000 BTU Per Boiler Horse Power Per Hour

4 to 6 per cent. The efficiency should not be less than 65 to 70 per cent for boilers equipped with mechanical stokers and using Colorado lignite coal, which means that the above named losses 1, 2 and 3 should not amount to more than 25 to 30 per cent.

Assuming a boiler efficiency of 70 per cent, a boiler pressure of 140 pounds, absolute (absolute pressure equals atmospheric pressure plus gauge pressure), a feed water temperature of 202° F. and a coal containing 9,500 B. T. U., then the amount of water evaporated per pound of coal is found as follows:

The effective heat used

$$\text{for evaporation is } 9500 \times \frac{70}{100} = 6650 \text{ B. T. U.}$$

The heat required for transforming one pound of water at a temperature of 202° F. to steam at an absolute pressure of 140 pounds is found by means of a steam table to be

$$1192.2 \text{ B. T. U.} - 169.9 \text{ B. T. U.} = 1022.3 \text{ B. T. U.}$$

The amount of water evaporated per pound of coal is then

$$\frac{6550}{1022.3} = 6.5 \text{ pounds.}$$

DRAFT

By draft is understood in Boiler House practice the force which tends to pull the air through the grates, boiler and flues. This force is produced by the action of the chimney as follows: If the gases within a stack be heated, each cubic foot will expand and the weight of the expanded gas per cubic foot will be less than that due to a column of cold air. This difference in pressure will cause a flow of gases into the base of the stack. In its passage to the stack the cold air must pass through the grates, fire bed and the boiler, and in turn becomes heated. This newly heated gas will also rise in the stack and the action will be continuous. The higher the stack is, the greater this difference will be. The draft, or difference in pressure, is measured in inches of water by a draft gauge. The following table and Plate No. 36 give the draft required in inches of water in the furnace for burning Colorado lignite in chain grate stokers:

COAL BURNED PER SQ. FT. OF GRATE SURFACE PER HOUR

Pounds	10	15	20	25	30	35	40	45
Furnace Draft	.15	.19	.14	.18	.24	.30	.37	.47

By means of the above table it is possible to tell approximately the amount of coal burned under the boiler when the draft and grate surface are known, and also the approximate load on the boiler if a certain efficiency is assumed. Thus if the draft is .30″ for a 350-H. P. B. & W. boiler with a grate surface of 80 sq. ft., then the coal burned is $35 \times 80 = 2800$ pounds per hour. Assume an efficiency of 70 per cent and a coal used containing 9000 B. T. U., then by using the chart on Plate 35 we find that $4.8 \times 10000/9000 = 5.33$ pounds of coal is required per boiler horse power hour. The boiler is thus, under above operating conditions, developing $2800/5.33 = 525$ Boiler Horse Power or 150 per cent of its rated horse power. It has been found that the best efficiency is obtained with chain grate stokers burning Colorado lignite coal when the boilers are operated with an overload of between 25 and 50 per cent, which means that the furnace draft should be between .25″ and .30″. The effects of low draft are low capacity and low efficiency. Very high draft gives high capacity but low efficiency.

The differential draft indicates the resistance of the boiler to the passage of the flue gases, and the sum of the furnace draft and the differential draft gives the total draft required for the operation of the boiler.

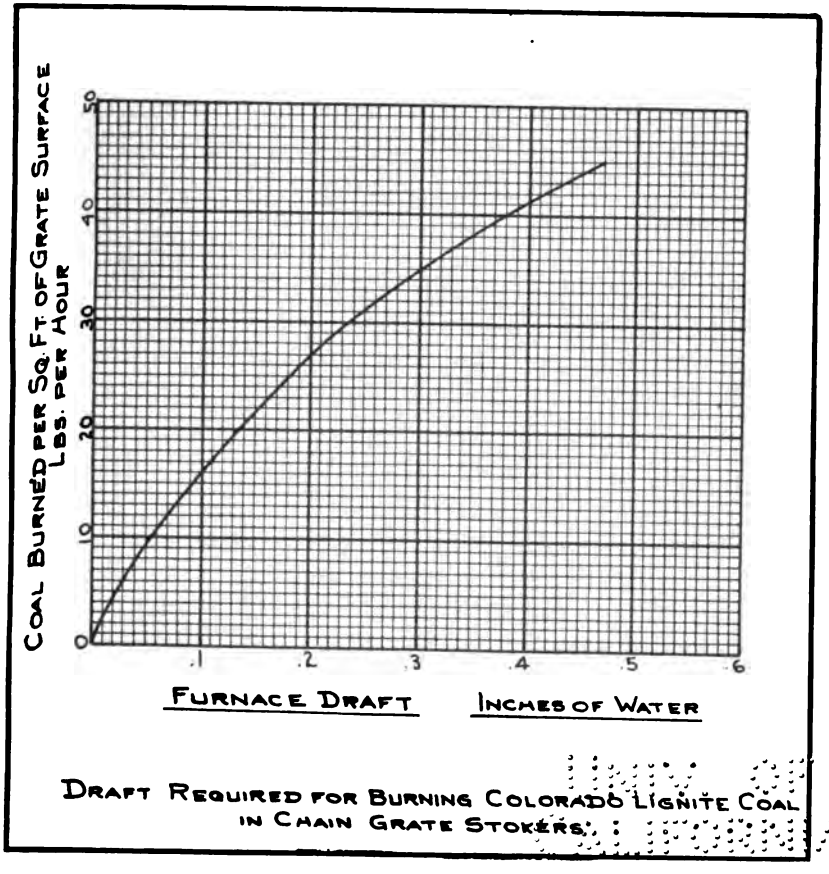
BOILER HOUSE CONTROL

Below are given the methods for obtaining the various samples and making the tests necessary for calculating the boiler house losses, and following these are given the formulas and methods for figuring these losses.

These calculations are made by the laboratory for each shift and are reported on the Daily Boiler House report. A sample of this report sheet is shown on Plate No. 37.

General.—No definite routine should be followed in the boiler house control work; irregularity in the time of sampling and testing the individual boilers will tend to give more nearly average results. The boiler house control man should take and prepare all the necessary coal and ash samples, make the flue gas analysis, and obtin the draft and temperature readings and any other necessary data. If a boiler house control man is not employed, the man in charge of unloading coal should take the coal samples, and the Assistant Chemist should obtain the ash samples; the other data on

Plate No. 36.



DRAFT REQUIRED FOR BURNING COLORADO LIGNITE COAL IN CHAIN GRATE STOKERS.

Plate No. 37.

DAILY BOILER HOUSE CONTROL

The Great Western Sugar Company

No._____ _____Factory 24 Hours Ending 7 A.M._____

FIREMAN	Boiler No.	DRAFT Average Furn.	DRAFT Diff.	AIR Temp °F	FLUE GAS Per Cent CO2 Individual Readings			FLUE GAS Average	FLUE GAS Temp °F	% ASH Stoker	% ASH Flume	PER CENT LOSSES Flue Gas Low CO2	Flue Gas Moisture	Flue Gas Total	Ash on Stoker	Total Loss
	1	.35	.49		-	10.4	12.0	11.2								
	2	.28	.53		-	12.0	12.6	12.2								
	3	.10	.10		-	11.6	-	11.6								
Doe	4	.23	.52		12.2	11.0	11.8	11.7								
	5	-	-		-	-	-	-								
	6	-	-		12.4	11.2	11.4	11.7								
Group West	Avg.	.24	.41	77	12.3	11.2	11.9	11.8	505	78.80		13.83	9.62	23.45	4.79	28.24
	7	.32	.45		12.0	11.2	12.0	11.7								
	8	.16	.48		11.8	12.2	12.2	12.1								
Allen	9	.30	.50		12.0	11.6	12.0	11.9								
	10	.32	.52		12.0	12.4	12.4	12.3								
	11	-	-		-	-	-	-								
	12	.27	.43		12.0	12.8	13.0	12.6								
Group East	Avg.	.26	.47	75	11.9	12.0	12.3	12.1	505	84.64		13.36	9.63	22.99	.99	23.98
Shift No1	Avg.	.25	.44	76	12.1	11.6	12.1	11.9	505	86.87	74.28	13.59	9.63	23.22	2.86	26.08
	1	.30	.41		12.6	14.0	13.4	13.3								
	2	.34	.46		11.2	-	-	11.2								
	3	.25	.36		13.6	13.4	12.8	13.3								
Smith	4	-	-		-	-	-	-								
	5	-	-		-	-	-	-								
	6	.29	.43		12.6	11.0	11.8	11.0								
Group East	Avg.	.30	.42	68	12.8	12.8	12.7	12.7	500	89.56		12.73	9.66	22.39	2.16	24.55
	7	.35	.43		12.6	14.2	13.2	13.3								
	8	.34	.47		12.6	12.0	13.0	12.8								
Bowen	9	.30	.44		13.0	13.4	13.6	13.3								
	10	.25	.38		13.4	11.8	14.2	13.1								
	11	.31	.48		-	13.2	14.2	13.7								
	12	.27	.46		11.4	-	-	11.4								
Group East	Avg.	.30	.44	70	12.6	12.9	13.6	12.9	500	89.76		12.42	9.64	22.06	2.01	24.07
Shift No 2	Avg.	.30	.43	69	12.6	12.9	13.2	12.8	500	89.66	69.36	12.59	9.66	22.23	2.07	24.30
	1	.36	.36		12.8	12.0	-	12.4								
	2	-	-		-	-	-	-								
	3	.29	.39		11.4	11.4	-	11.4								
Jones	4	.33	.37		9.0	9.6	10.4	9.7								
	5	.38	.52		-	11.8	11.4	11.6								
	6	.31	.47		11.6	12.4	12.6	12.2								
Group West	Avg.	.33	.42	55	11.2	11.4	11.5	11.4	473	88.48		13.36	9.59	22.96	2.29	25.24
	7	.34	.45		13.0	12.0	12.2	12.4								
	8	.50	.57		11.4	11.0	12.0	11.5								
Hall	9	.43	.57		11.0	11.8	14.4	12.4								
	10	.29	.39		11.0	10.2	10.0	10.4								
	11	.41	.59		12.0	12.0	11.4	11.8								
	12	-	-		-	-	-	-								
Group East	Avg.	.39	.51	57	11.7	11.4	12.0	11.7	473	88.78		14.91	9.64	24.55	2.22	26.79
Shift No3	Avg.	.36	.47	56	11.5	11.4	11.8	11.6	473	88.60	77.72	14.14	9.62	23.76	2.25	26.00
24 Hours	Avg.	.30	.45	67	12.3	11.9	12.3	12.1	493	88.26	73.78	13.44	9.63	23.07	2.39	25.46

% Coal on Sugar to Date.....100.27..
Tons Coal Burned Today.....382.....
Coal B.T.U. Average to Date.....9173.....
Coal, % Ash, Average to Date.....11.01..
Coal, % Moisture, Average to Date....16.87..

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flue gas analysis and temperature, draft, etc., will not be obtained except for what average figures are available from the recording instruments.

Sampling of Coal.—Use a sampler consisting of a piece of 2 inch pipe about 4 feet long, provided with a spring valve at one end to retain the coal in the sampler. (See Plate No. 38.) Sample all cars unloaded, just previous to unloading, by driving the sampler through the coal in the car and collecting the coal retained in the pipe. Take three samples from each car, one in a corner about two feet equally distant from the sides of the car, one in the center of the car, and one in the corner diagonally opposite the position of the first sample. Preserve all the samples in a can provided with a tightly fitting cover, such as a milk can. or in a number of such containers, and keep in a cool place.

Sample cars loaded from the storage pit in the same manner as cars received from the mine; if coal is hauled from the storage piles, take one sample from every fifth wagonload. Take no samples from cars loaded from drippage pit or from cars into which drippage has been loaded. Pay special attention to this point to avoid contaminating the regular sample with drippage. If coal from different sources (mine, storage pit, etc.) is being used, include in the gross sample amounts from each source in approximate proportion to the amounts from each source used.

Sample the coal used in the pulp dryer in exactly the same manner. The sampling should be done in this case by the man who unloads the coal for the dryer but should be under the supervision of the boiler house control man.

Preparation of Coal Samples.—When all the coal for a day's use has been sampled, crush the entire gross sample to ¼ inch size and reduce to 1 to 2 quarts by mixing and quartering on a large piece of canvas; do this as rapidly as possible to avoid loss of moisture. Keep the sample in a fruit jar closed with a tightly fitting cover provided with a rubber gasket.

At the end of the week grind the entire seven samples representing the week's run of coal to 60 mesh size in the pebble mill, which should contain 100 pounds of flint pebbles and run at the rate of 50 to 60 revolutions per minute. Put up and seal a 4 oz.

sample of the ground material, and forward it without delay to the central laboratory for analysis. Be careful to clean the mill thoroughly after each week's sample is prepared, and employ it exclusively for grinding coal.

Sampling of Ashes

(1) In Boiler House Equipped With Chain Grate Stokers:

Obtain samples of grate and flume ashes as follows:

(a) *Grate (Stoker) Ash:* Use the type of sampler illustrated on Plate No. 38, consisting of a rectangular box with hinged cover fastened to a long handle. Obtain three samples per shift, if possible, from the discharge of each stoker in operation, taking sufficient quantity so that the total sample for the eight hours will amount to about one gallon. Save separate samples for each shift for each set of boilers in charge of each fireman. This will make six samples per 24 hours at the large factories and three at the small factories.

(b) *Flume Ash:* Obtain the sample by holding a closely woven sack over the discharge of the flume ash line, or over the special sampler provided for this purpose, in such a manner as to obtain an average of all solid material delivered through the line. Take a sample at least twice a shift and make up a composite sample for each shift by mixing at least one quart of each of the individual samples.

(2) In Boiler Houses Equipped With Hand Fired Furnaces:

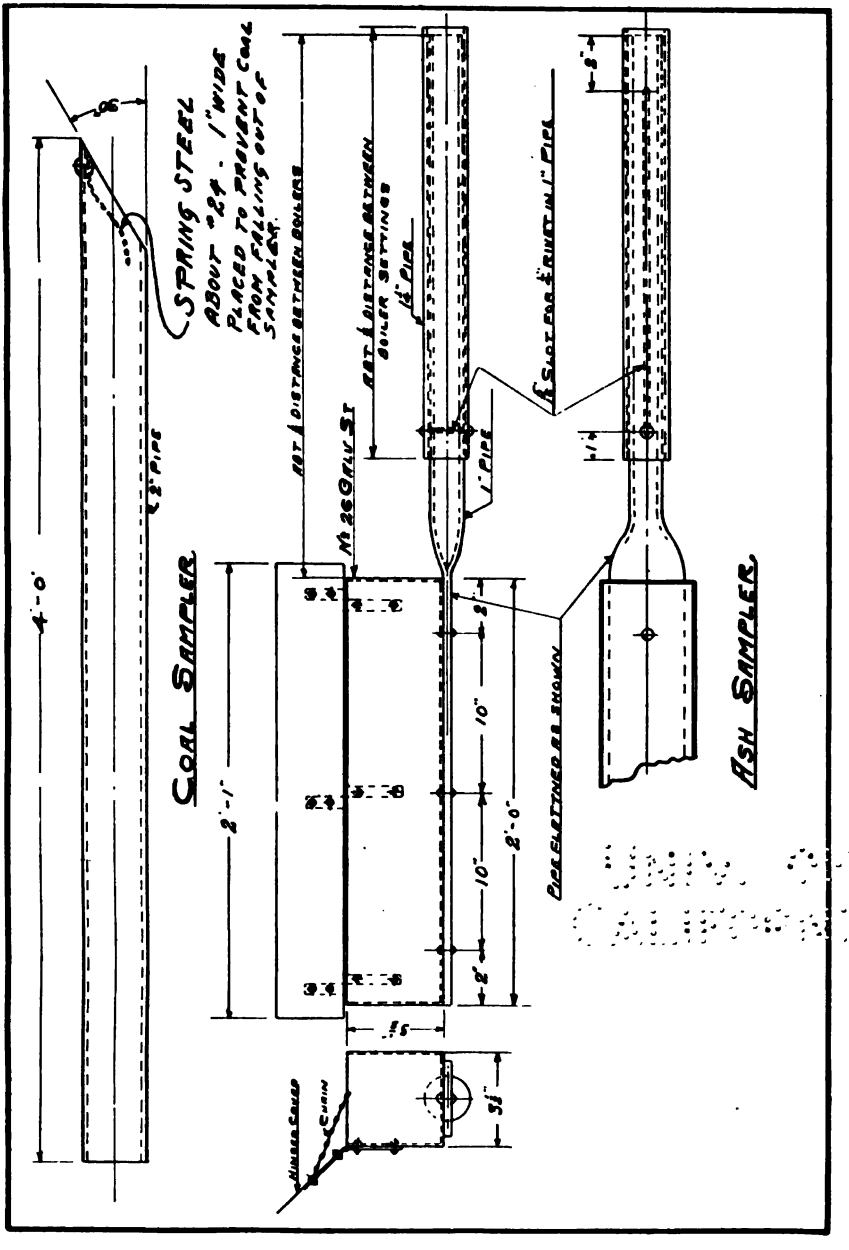
Obtain samples of pan, grate, and flume ashes as follows:

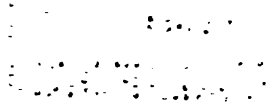
(a) *Pan Ash:* Take a small sample of the ash in the pan of each boiler in operation at least three times per shift; the total sample for the shift should be about one gallon. Save separate samples for each shift. If a boiler house control man is not employed, obtain one quart sample once a shift representing an average of the ash in the pans at the time of sampling.

(b) *Grate Ash:* Take samples only when the fires are being pulled and before the ash is wet down. Obtain an average sample of at least one gallon once a shift, or oftener if a boiler house control man is employed. Crush the gross sample to break up large lumps, mix, and save one quart sample representing the work of each shift.

(c) *Flume Ash:* Obtain at least three times a shift as described in (1), (b), above. If a boiler house control man is not employed, obtain at least once a shift.

Plate No. 38.





(3) In Pulp Dryers:

The boiler house control man or the Assistant Chemist should obtain an average sample of the grate ash at least once per shift, as described in (1), (a).

Preparation of Ash Samples.—Break up any large lumps by crushing, mix well, take out one quart and crush to 10 mesh size in a jaw crusher. Mix the crushed sample and grind at least one-fourth of it to 60 mesh size in a disc pulverizer. Mix well and save 4 ounces for analysis.

As the samples of ash are analyzed on a dry basis, no care need be taken to avoid loss or gain of moisture during the preparation of the sample. Any samples which are very wet, however, such as the flume ashes, should be dried in a shallow tray in a warm place before being prepared for analysis.

If the special boiler house control is carried on, the sample of ashes collected to represent the work of each shift should be analyzed separately. Otherwise a composite sample of each kind of ashes should be prepared at the end of every week and sent to the central laboratory, together with the coal sample, for analysis.

Draft.—Take draft readings, both "furnace" and "differential," on the individual boilers at the time when samples of the grate ash are collected. Check all the draft gauges at the zero point at least once a shift, and test all connections for air leaks frequently.

The liquid used in Ellison and in Blonck differential draft gauges is, unless otherwise specified, mineral oil of .834 specific gravity at 60° F., colored red or blue. The best temporary substitute is kerosene, having nearly the same specific gravity. Water must not be used.

Flue Gas Analysis.—Immediately after the ash sample is taken and the draft readings are made, determine the percentage of carbon dioxide in the flue gas, using either the Hays or the Orsat apparatus. Change the caustic alkali solution every two days. The addition of a few drops of phenolphthalein to the water in the measuring burette will be of value to indicate contamination from the alkali solution. Rinse out the sampling pipe thoroughly before drawing gas into the apparatus.

The gas sampling pipe should pass through a hole drilled in the brickwork, and the open end through which the gas enters should be close to the point where the gases leave the boiler and where the velocity of the gas stream is a maximum. Leakage around the sampler should be stopped with asbestos packing. The proper position of the sampler is of great importance.

Temperature of Air and Flue Gas

(1) Air Entering Furnaces:

Take readings, at the time when the flue gas is analyzed, of thermometers in different parts of the boiler room hung near the point where the air enters below the stokers but not so close that they will be heated by radiation from the fire.

(2) Flue Gas:

If the boilers are equipped with individual thermometers or if the apparatus is available, determine the temperature of the flue gas at the time when the gas is analyzed. If only a general recording instrument is available, take several readings during the period of ash sampling and gas analysis, and use the average of these readings as a basis for figuring the heat loss.

Calculation of Heat Losses

(1) Data Required:

(a) *Moisture, Ash, and Calorific Value of Coal.* On account of the fact that the results of the coal analysis are not available until several days after the samples are taken and then only for weekly samples, use the average analysis to date of the coal burned during the campaign, recalculating these averages when each new set of figures is received from the central laboratory. During the first few days of the campaign, or until figures have been received from the central laboratory, use the average coal analysis of the preceding campaign.

(b) *Carbon and Hydrogen in Coal.* Use average figures obtained from the analysis of the Bureau of Mines. See Table II, page 215.) For northern Colorado lignite (sub-bituminous) coal the percentage of carbon may be taken as 57 and the percentage of hydrogen as 6, if the amount of combustible is approximately 75 per cent.

(c) Other data required are obtained from the daily determination.

(2) Loss in Dry Flue Gas:

Obtain from the chart (Plate No. 39) the "B. T. U. lost in dry flue gas per pound of carbon burned," according to the average flue gas analysis, and the average temperatures of the air and of the flue gas.

Let B = B. T. U. found from the chart
A = Calorific value (B. T. U.) of the coal as fired
C = % carbon in coal as fired
L_1 = Percentage loss of heat in dry flue gas

Then $L_1 = \frac{C\,B}{A}$

EXAMPLE

Assume 12 per cent CO_2 in flue gas and temperature of 500° F., boiler room temperature of 80° F., and 9,000 B. T. U. in coal containing 57 per cent carbon. From the chart T — t = 420, and B = 2,120.

$$L_1 = \frac{57 \times 2120}{9000} = 13.4\%$$

(3) Loss Due to Moisture:

The loss due to moisture is composed of:

(1) Loss due to moisture in the coal as fired.

(2) Loss due to moisture resulting from the burning of the hydrogen component of the fuel.

In addition to the symbols previously used,

Let M = % moisture in coal as fired
H = % hydrogen in coal as fired
T = Temperature (°F.) of flue gas
t = Temperature (°F.) of boiler room
w = Boiling point (°F.) of water (202° for 5000′ elevation and 205° for 3800′ elevation)
L_2 = Percentage loss of heat due to moisture

Then $L_2 = \frac{M + 9H}{A} \times \left[(w - t) + 976.6 + .47\,(T - w)\right]$

EXAMPLE

Assume, in addition to the figures in the preceding example, 16 per cent moisture and 6 per cent hydrogen in the coal, and boiling point of water as 202° F.

$$L_2 = \frac{16 + 54}{9000} \times 122 + 976.6 + 140.1 = 9.6\%$$

(4) Total Loss in Flue Gas:

If L_3 = total percentage loss of heat in flue gas
Then $L_3 = L_1 + L_2$

EXAMPLE

$$L_3 = 13.4 + 9.6 = 23.0\%$$

(5) Loss Due to Combustible in Ash:

This is based on the analysis of the coal and of the grate (stoker) ashes, the combustible matter in the ashes being assumed to consist of pure carbon of a calorific value of 14,600 B. T. U.

Let D = % ash in coal as fired
E = % ash in ashes
L_4 = Percentage loss of heat due to combustible in ash

Then $$L_4 = \frac{14600\ D\ (100 - E)}{A\ E}$$

Or if $k = \frac{14600}{A}$ a factor which can be used for a number of calculations.

Then $$L_4 = k \times \frac{D\ (100 - E)}{E}$$

EXAMPLE

Assume the coal to contain 12 per cent ash, and the ashes 60 per cent ash.

$$L_4 = \frac{14600 \times 12 \times 40}{9000 \times 60} = 13.0\%$$

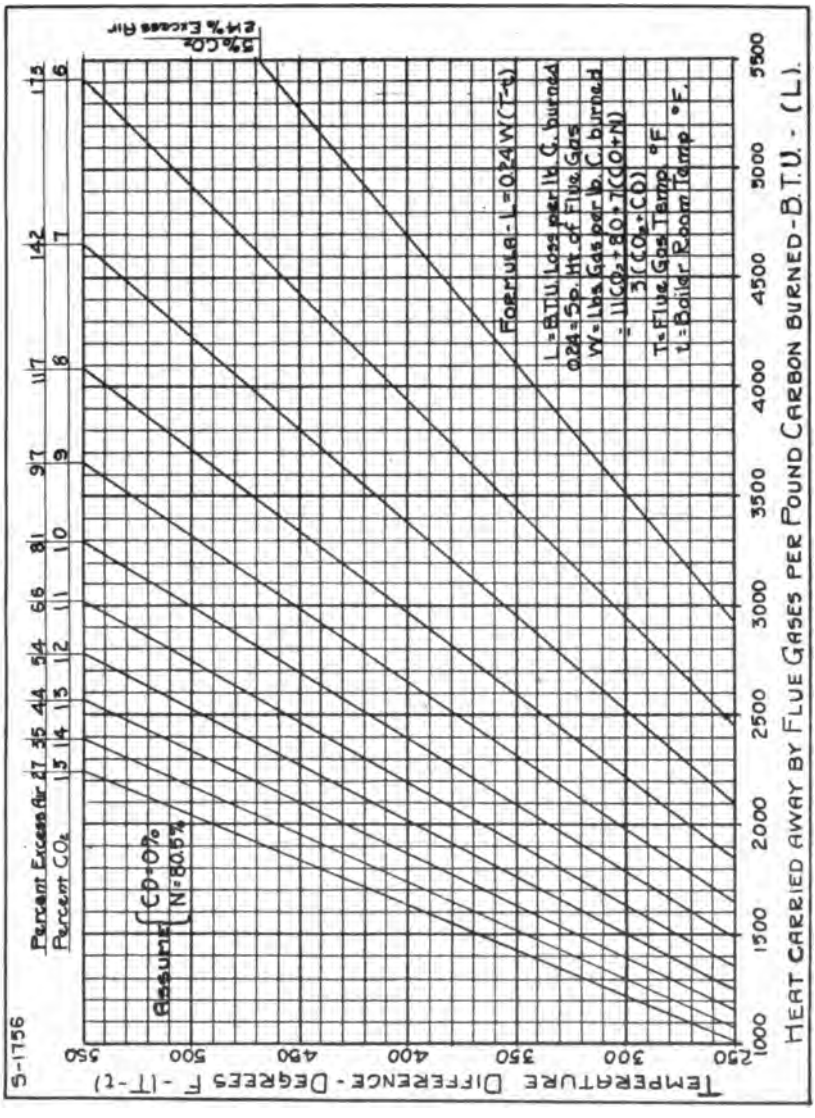
(6) Total Known Losses:

If L_5 = total known heat losses,
Then $L_5 = L_3 + L_4$

EXAMPLE

$$L_5 = 23.0 + 13.0 = 36.0\%$$

Plate No. 39.


S-1756
TEMPERATURE DIFFERENCE - DEGREES F. (T-t)
HEAT CARRIED AWAY BY FLUE GASES PER POUND CARBON BURNED - B.T.U. - (L).
Percent Excess Air 47 35 24 15 14 13 12 11 10 9 8 7 6
Percent CO2 15 14 13 12 11 10 9 8 7 6 5
Assume (CO+O2%) (N=80.5%)
Formula - L = 0.24 W (T-t)
L = B.T.U. Loss per lb. C. burned
0.24 = Sp. Ht. of Flue Gas
W = Lbs. Gas per lb. C. burned
= 11(CO2+8O+7(CO+N)
3((CO2+CO)
T = Flue Gas Temp. °F
t = Boiler Room Temp. °F.

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PROBLEMS

(1) What is the boiler efficiency when the flue gas contains 11 per cent CO_2, the flue gas temperature is 475° F., the boiler room temperature 70° F., the ash in the ash is 65 per cent and the radiation and unaccountable losses are assumed to be 5 per cent? The coal has the analysis given in Table II, page 215.

(2) A boiler has a rated capacity of 266 H. P. and is equipped with a chain grate stoker having a grate surface of 67 sq. ft. Calculate the load on this boiler in per cent of rated H. P., (a) when the draft over the fire is .14″ water and the boiler efficiency is assumed to be 50 per cent, (b) when the draft over the fire is .37″ water and the efficiency 69 per cent. The coal fired under the boiler contains in both cases 9,450 B. T. U. per lb.

(3) What is the theoretical weight of air required for the complete combustion of a coal having the following ultimate analysis: Carbon 74 per cent, Hydrogen 4.98 per cent, Oxygen 6.43 per cent, Nitrogen 1.20 per cent, Sulphur 3.24 per cent, Water 1.55 per cent and Ash 7.82 per cent?

(4) A boiler having a rated capacity of 350 H. P. is operated under a load of 130 per cent. The feed water has a temperature of 175° F. and the boiler efficiency is 64 per cent. How many pounds of coal having a heat value of 9,300 B. T. U. per pound are required for this boiler per hour?

(5) The boiler specified in Problem 4, has a chain grate stoker with 80 sq. ft. grate surface; what is the approximate draft required?

(6) How many boiler horse power are required for running hot saccharate at a factory working 160 tons of molasses per twenty-four hours under the following conditions: Amount of waste 263 cu. ft. per ton of molasses, temperature to be raised from 15° C to 85° C.?

(7) How many tons of 9,500 B. T. U. coal are required for hot saccharate per twenty-four hours under the conditions stated in Problem 6?

(8) How many 350 H. P. boilers, operating at 150 per cent of rated capacity will be required for a factory which uses 85 per cent steam on beets while slicing 1,300 tons per day?

(9) How many gallons of boiler feed water will be required per minute for the boilers in Problem 8?

(10) How many tons of ashes are handled per day by an ash pump in a factory burning 300 tons coal per day, the ash content of the coal being 7 per cent and the ash content of the ash being 70 per cent? 90 per cent?

(11) Assuming 15 per cent drippage through the grates, how many tons of coal drippage must be handled per day in a factory using 300 tons of coal per day?

CHAPTER NO. XIV

THE PULP DRYER

SECTION A

The pulp dryer takes the pulp from the main factory as it leaves the battery and reduces it to an apparently perfectly dry condition. Like other vegetable products, however, dried pulp actually contains about 12 per cent moisture. By this process the pulp is put into a condition in which it will keep indefinitely without fermentation and is suitable for shipment.

Probably the most important point to be remembered in connection with pulp dryer work is that the dryer is in reality a part of the beet end. Inasmuch as all pulp produced must be dried and the pulp pit under the battery is the only storage, it is evident that the factory can continue to slice beets only for about half an hour after the dryer has been out of operation. In addition to this the effect of small changes on the battery, such as temperature, knife setting, etc., will be immediately noticed in the dryer. In fact the battery must be run within certain limits to suit the dryer, and if the beet end foremen do not keep this in mind, trouble is sure to follow. This is not so true of factories having a surplus of drying capacity, but most of our drying plants have only two drums, and if the pulp is not delivered to the dryer in the best of condition, the drying plant will soon reduce the rate of slicing of the main house.

WATER SEPARATOR

The pulp is pumped from the main factory to the dryer and it has been found to be equally as important that the pulp pumps be not too large as it is that they be not too small. The pulp must come to the dryer in fairly uniform quantities for best work of the dryer. The wet pulp is either received at the dryer in a water separator, where it drains to a certain extent before being conveyed to the wet pulp drag, or is discharged directly upon a pulpefanger. The water separator is a water-tight receiving tank open at the top and provided with a perforated metal sheet at the bottom. This allows the excess water to drain off, while the pulp, which is retained by the perforated metal sheet, is conveyed out of the separator by means of screw or drag conveyors to the pulp presses. The pulp leaving the water separator contains about 95 per cent water and its weight is approximately equal to the original weight of beets, or 100 per cent of the beets sliced.

PULP PRESSES

The pulp entering the presses contains about 95 per cent water, or 5 per cent dry substance, and the pulp leaving the presses contains about 85 per cent water, or 15 per cent dry substance. Calculation will show that this is equivalent to saying that approximately 70 per cent of the water contained in the original pulp is eliminated by the presses. This is attended with a small unavoidable loss of dry substance due to the fine particles of pulp which are carried out in the press water and are not caught by the pulpefanger over which the latter passes. To show the importance of good work on the pulp presses it may be calculated that for a factory slicing 1,200 tons of beets per day the daily coal consumption in the dryer will be approximately 10 tons more per day if the pressed pulp contains 85 per cent moisture than it would be if the moisture content were reduced to 82 per cent.

The press station consists of a number of pulp presses placed in one or more rows, each press being a complete unit in itself. The pulp press consists of a hollow rotating cone which revolves at the rate of 3½ to 4 R. P. M. and is covered with a fine screen. On the outside of this cone are arms or segments of flights, which convey the pulp through the press. Around the outside of this revolving cone is a screen cylinder through which iron rods or arms project which keep the pulp from turning with the cone. At the large end of the cone, or the outlet end of the press, is an adjustable conical ring which regulates the size of the opening through which the pressed pulp is discharged. The pulp press receives the pulp at the small end of the revolving cone, where there is considerable space between it and the outside screen cylinder. As the pulp moves through the press it is constantly forced into a smaller space so that a large quantity of water is squeezed out both through the screen on the hollow cone and through the outside screen cylinder.

DRYING DRUMS

In some installations the pulp leaving the presses in run through pulp cutters, which consist of two rows of small circular saws revolving toward each other. This produces a product of uniform size which is easy to dry and pack. The pressed pulp is now conveyed and fed to the dryers proper, commonly called the drying drums. There are two general classes of dryers, the steam dryer and the fire dryer. The Great Western Sugar Company's installations are of the direct heat, or fire dryer, type and consist in general of a furnace, a large revolving steel drum, a suction fan to draw the furnace gases and pulp through the drum, and a dust

cyclone to separate the spent gases from the fine particles of dried pulp. In the steam dryer the pulp is brought into contact with hot steam pipes and the necessary quantity of air is drawn through the dryer. The product produced by the steam dryer is light colored and there is no chance of its ever being burned or charred, but the first cost of this type and the expenses for maintenance are both high.

The furnace of the fire dryer is very similar to the ordinary Dutch oven with a large combustion chamber in the rear which allows the ash and light coal to deposit from the furnace gases before they enter the dryer drum. These furnaces are equipped with stokers, the most common type being a chain grate stoker. This type of stoker is very flexible for the reason that if a high heat is required, the entire length of the grate can be used, and as less heat is required, the fire can be shortened by using only a part of the length of the grate and yet a large quantity of heated gases, almost free from smoke, will pass into the dryer drum. In the sides of the combustion chamber are air ports equipped with doors which regulate the amount of air that is mixed with furnace gases. It is not as important to keep the percentage of CO_2 as high in the furnace gases as in steam boiler practice for two main reasons: first, under ordinary conditions extremely high temperatures are not needed in the dryer, while at the same time there has to be enough air passing through the dryer to carry off the moisture and still not be saturated with respect to moisture at a temperature of about 180° F.; second, the temperature of the exhaust gas is only about 180° F., as compared with about 550° F. for the flue gas of a boiler.

In the top of the combustion chamber is an auxiliary stack with a tight damper at its base. This stack is used only when the dryer is shut down and allows the gas from the furnace to escape without passing through the dryer.

All modern pulp drying plants are equipped with coal crushing and conveying machinery so that the furnaces are supplied with a uniform sized coal, and, since they consume considerable coal (from 60 to 100 per cent coal on dried pulp according to the moisture content of the pressed pulp and the heat economy of the drum), coal handling machinery is a saving proposition.

The revolving dryer drum, or dryer, consists of a steel shell filled with a honeycomb of sheet steel shelves, or heating trays, the whole drum being mounted on trunnions and revolving at the rate of 2 to 3½ R.P.M. At the discharge end of the drum is a stationary housing connected to a large suction fan which pulls the gases

through the furnace and then through the dryer and discharges them, with some fine particles of dried pulp, into a cyclone where the gases and fine pulp are separated.

Two kinds of dryers are in common use, namely, the single pass and the double pass dryer. The single pass drum receives the pressed pulp and the hot gases from the furnace at one end and discharges the spent gases and the dried pulp at the opposite end. The double pass dryer consists of a drum within a drum, both turning as one unit. The pressed pulp and the furnace gases enter at one end of the inner drum and are discharged at the opposite end into the outer drum. They then pass through the outer drum from which they are discharged at the end next to the furnace. Both the single and the double pass drums are filled with a honeycomb of sheet steel shelves, or heating trays, all set parallel to the axis of the drum. The single pass dryers are eight feet in diameter and thirty-nine feet long. The inner shell of the double pass drums is seven feet six inches in diameter, while the outer drum is eleven feet in diameter and thirty-three feet long. The capacity of each type of dryer being about the same, the time required for the pulp to pass through the dryers is also about the same. The shelves in the single pass drum are closer together and the drum revolves more slowly than the double pass drum, so that it takes the pulp as long to travel thirty-nine feet through a single pass drum as it does to travel sixty-six feet through the two passes of the double pass drum. As the drum revolves slowly (2 to 3½ R.P.M.), the pulp is constantly moving from one hot tray to another and at the same time falls only a short distance so that the current of gases does not move the pulp through the drum very fast. Every tray or shelf in the drum is filled with pulp and the hot gases passing through the drum keep the trays heated as well as carry away the moisture. This method of drying pulp is used because most of the moisture in pulp is contained in very small plant cells of the original beet and not on the surface as in the case of sugar. As a pulp dryer drum is set level the only thing that carries the pulp through the drum is the current of furnace gases.

As stated before, the hot furnace gases and the pressed pulp enter the dryer together. The quantity of furnace gases that is drawn into the dryer is regulated by a damper on the suction side of the dryer suction fan. The quantity of pressed pulp introduced into the dryer is regulated by a variable speed screw conveyor which is located in the bottom of a large hopper. The object of the hopper is to keep the feed scroll full of pulp at all times and thereby give a uniform feed to the dryer.

By means of a recording pyrometer on the combustion chamber of the furnace, the operator is able to determine the temperature of the gases entering the dryer, and, by means of a recording thermometer in the housing over the discharge end of the dryer, the operator is able to determine whether more or less pressed pulp should be introduced or the temperature of the furnace gases increased or decreased.

The moisture in the pulp is reduced in the drying drum from about 82-85 per cent (pressed pulp) to about 12 per cent (dried pulp).

When dried molasses pulp is produced, a stream of hot discard molasses is run into the feed scroll which conveys the pulp to the dryer. By means of this scroll the pressed pulp and molasses are mixed before they enter the dryer. For heating this molasses a water back is installed on the chain grate stoker, or a pipe coil is installed in the combustion chamber of the furnace, either one of which serves to heat water which in turn is circulated through pipe coils in the molasses heating tanks.

PACKING

The dried pulp, after it is discharged from the dryer, together with the fine pulp which has been separated from the spent gases, is conveyed by machinery or by air to the packing station.

The packing station consists of a number of automatic weighing and packing machines placed in a row and fed by a screw conveyor overhead. Each of these machines weighs up the required quantity, generally one hundred pounds, of dried pulp and discharges it into the packer which packs the pulp into a single burlap bag. The packer consists of a vertical shaft with a packing auger at the bottom, the whole enclosed in a housing. The burlap bag is placed inside of a moving housing which telescopes the packing auger housing. As the auger packs the dried pulp in the bag, it keeps forcing the bag and bag holder down until the required amount of pulp is packed in the bag. The bag is then removed from the holder, sewed by hand, rolled upon a belt conveyor, and carried to the warehouse where it is piled and stored in a similar manner to sugar.

The pulp dryer fireman holds the most responsible station position in the drying house as it is his duty to regulate the fire and feed on the drums so that pulp of the proper moisture content will be produced and at sufficient capacity. He must watch constantly the temperature of the gases entering and leaving the drums and

for coal economy must keep the temperature of the gases leaving the drums as low as possible.

As, at the best, it requires an hour or more to make a moisture determination in the laboratory, these determinations are valuable principally as a record and to teach men the "feel" of pulp dried to the desired point. The experienced dryer foreman or fireman can determine, by feeling the pressed pulp, just about what conditions must be maintained to dry it, and, by feeling the finished product, he guesses the moisture content with wonderful accuracy.

Only enough air should be admitted through the air ports of the furnace to dry the pulp properly; an excess of air wastes coal, and insufficient air, regardless of the heat carried, will not dry the pulp.

Serious fires have occurred in the pulp drums, due to the fact that the pulp in the drums becomes too dry, takes fire and burns. The most efficient method of fighting these fires is through the admission of steam to the drum. When the temperature of the gases leaving the drums begins suddenly to increase, it indicates an insufficient feed of wet pulp to the drums, and fire, or at least great danger of fire. The operator should without delay assure himself that the pulp is feeding, and, if the temperature continues to increase, he should cut off some of the draft from the dryer suction fan, turn steam into the drums if steam is available, and increase the feed of wet pulp. All draft from the fans should not be cut off, as it is this draft which pulls the wet pulp forward into contact with the portion of the drum which is too hot.

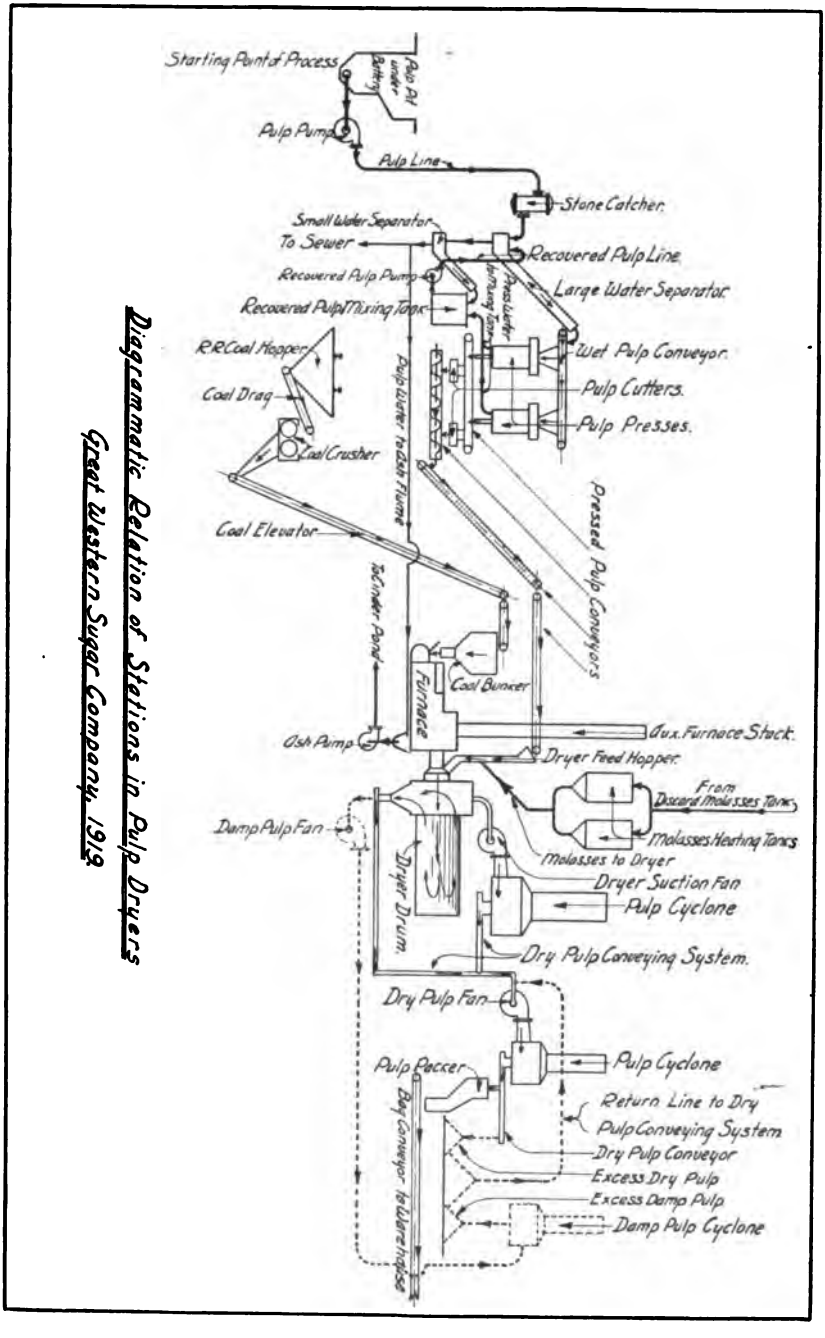
SECTION B

ELIMINATION OF WATER BY PULP PRESSES

It is very important that the pulp leave the presses with as low a moisture content as possible, and to obtain this result it is necessary to observe and regulate the battery work very carefully. For best results the pulp should enter the presses at a temperature of 45° to 55° C. Lower temperatures, while producing pulp of good moisture content, do so at the expense of capacity; and a high temperature, while it increases the output of the presses, usually produces a pulp of high moisture content. This relates not only to the temperature of the pulp entering the presses but to the temperature of the whole battery, and in this connection the speed of the battery plays an important part.

As a general rule, low battery temperatures are desirable for good pulp dryer work, that is to say, low maximum temperatures.

PLATE NO. 40.



Diagrammatic Relation of Stations in Pulp Dryers

Great Western Sugar Company, 1919

If beets of good average quality are being sliced, such as might be worked with a temperature of 83° to 85° C. in a non-pulp dryer factory, then the pulp dryer factory would probably work such beets at a temperature of 78° to 80° C., and might also carry this temperature over a smaller number of cells. All this is again dependent on the speed of the battery, as a good firm chip with a fast battery can obviously stand a higher temperature than would be possible if the chip were subject to the same temperature for a longer period of time. The knife setting and the perfection of the cossettes also have a great influence, although these are in one sense covered by remarks on the speed of the battery. A heavy chip will stand a higher temperature than a very thin slice. All of the above factors, and also the quality of the beets being worked, will be found to need attention. No hard and fast rules can be laid down, as each set of conditions require a separate analysis.

In a dryer equipped with three drums it is possible to handle much wetter pulp from the presses, and, while this may require more coal in the dryer, it may result in better coal economy from the standpoint of the factory as a whole, for in general, the conditions which produce a pulp of better moisture content in the dryer do this at the expense of an increased battery draft. In drying plants having only two drums the capacity question is vital, and, if the pulp is allowed to come from the presses too wet, there will be times when it cannot be dried as fast as it is produced.

LABORATORY CONTROL OF LOSSES

From the standpoint of the control of losses, the laboratory control of pulp dryer work is of necessity very imperfect, as we have no data showing the actual amount of dry substance in the pulp entering the dryer and hence have no knowledge of the extent of losses.

The mixture of pulp and water entering the dryer contains many fine particles of pulp which pass through the water separator screen and are squeezed out through the pulp press screens. To minimize this loss, the water from the presses, and sometimes also the water from the separator, is discharged upon a pulpefanger which in turn delivers into the drag feeding the presses, but even at the best the refuse waters contain some fine particles of pulp. If large pieces of pulp are found present, the screens should be immediately examined for holes.

MOISTURE IN SACKED PULP AND MOLASSES CONTENT OF DRIED PULP

The question of the correct moisture content of pulp as sacked and sold has been given considerable thought and study, and fac-

tories now strive to produce pulp containing about 12 to 14 per cent moisture, but this question of moisture has lately been found to be intimately connected with the percentage of molasses present in the pulp.

The laboratory reports two figures which require explanation: (1), "Plain Pulp Equivalent" is the amount of pulp which would have been produced at the prevailing moisture content if no molasses had been added. (2), "Per Cent Molasses in Molasses Pulp" is the proportion by weight of the pulp sacked which had its origin in molasses. For example, if dried molasses pulp contains 20 per cent molasses it means that of the dry substance present in the dried pulp sacked, 20 per cent of it has been introduced in the form of molasses and 80 per cent in the form of actual pulp. The amount of molasses added to pulp varies, as some sections and some buyers desire a high molasses content and others stipulate that the molasses shall not exceed a certain percentage. During the campaign of 1919-20 pulp was produced containing from 20 to 40 per cent molasses, this last being mostly for experimental purposes, as it was desired to know if the high molasses pulp would keep without danger of mold or fire from spontaneous combustion. While more data is needed in order to reach definite conclusions, it is probably true that there is no danger from fire or mold if the moisture content of the pulp is correct, but the greater the percentage of molasses used, the lower must be the moisture content of the sacked pulp. For example, plain pulp will keep nicely with as high as 14 per cent moisture or even more, but a high molasses pulp is wet and gummy with this amount of moisture present. For a 40 per cent molasses pulp it is probable that the moisture should be carried as low as 10 per cent. This is not alone on account of the danger from mold and spontaneous combustion, but also on account of the danger of caking in the sack, especially in the bottom of piles where the sacked pulp is subject to considerable pressure.

It is important, however, not to carry the moisture unnecessarily low, first, because if carried too low the pulp will take up moisture in the warehouse to a certain extent and therefore coal is expended for nothing; second, too low moisture increases the loss from dust and produces a dusty, hard, dry product not desired by the purchaser, and third, there is considerable loss of revenue as less actual weight of pulp is produced. According to actual campaign data, factory "A" had an average moisture content of 10.9 in its dried pulp and factory "B" 11.9 per cent. If factory "A" had produced pulp containing the same percentage of mois-

ture as factory "B", it would have produced approximately 90 tons more pulp, which at $30.00 per ton would be worth approximately $2,700.00, with an additional saving in coal.

SUPERVISION

As the pulp drying plant is usually located at some distance from the main factory, this adds greatly to the difficulty of management and also to the difficulty of operation. The pulp must be pumped to the dryer, and, as the distance increases, the difficulty of obtaining smooth, continuous operation also increases.

The distance of the drying plant from the main factory also adds greatly to the difficulty of supervision, and it cannot be too strongly emphasized that the dryer is to be considered a vital part of the beet end and not a separate process. If this fact is lost sight of, the main factory will be subjected to delays charged to pulp dryer that would not have existed had the supervising men considered the dryer in its true position.

PROBLEMS

Pulp Presses.—The following formulas are useful for estimating the efficiency of the pulp presses:

Let A = % moisture in wet pulp entering presses
B = % moisture in pressed pulp
C = % dry substance in water from pulp presses
W = % water removed in presses, of water originally present
L = % dry substance lost in press water, of dry substance originally present

$$\text{Then } W = \frac{100\ (A - B)\ (100 - C)}{A\ (100 - B - C)}$$

$$\text{And } L = \frac{100\ C\ (A - B)}{(100 - A)\ (100 - B - C)}$$

(1) The wet pulp entering the presses contains 95 per cent moisture, the pressed pulp 85 per cent moisture, and the press water 0.4 per cent dry substance. What percentage of the water is removed in the presses and what percentage of the dry substance is lost? Answer to second question: 5.48.

(2) On account of holes in the pulp press screens which are not given attention, the percentage of dry substance in the press water increases to 0.7. What additional percentage loss of dry substance is caused thereby?

(3) If the additional loss calculated in (2) were allowed to go on for a 100-day campaign, what would be the equivalent loss in bags of dried pulp? Assume a factory slicing 1,300 tons of beets per 24 hours and producing 5.0 per cent dried pulp on beets, containing 12 per cent moisture.

EXPLANATION:—The factory produces

$$1{,}300 \times .05 = 65 \text{ tons dried pulp per day}$$

$$65 \times \frac{(100 - 12)}{100} = 57.20 \text{ tons dry substance per day}$$

The amount of dry substance present in the wet pulp in example (1) is

$$\frac{57.20 \times 100}{100 - 5.48} = 60.51 \text{ tons dry substance per day}$$

Calculate then the additional loss of dry substance, in example (2), in terms of bags of dried pulp for a 100-day campaign. Note that 1 part of the dry substance is equivalent to $\frac{1}{.88} = 1.14$ parts of dried pulp containing 12 per cent moisture.

(4) If in example (1) the percentage of moisture in the pressed pulp were reduced to 84 instead of 85 per cent, what additional percentage of the water originally present would have been removed?

Drying Drums:

(5) A factory produces 50 tons of dried pulp per day containing 13.0 per cent moisture. The pulp entering the drums (leaving the presses) contains 86 per cent moisture. How many tons of water are evaporated per day in the drums?

ANSWER:—The amount of dry substance in the dried pulp is

$$50 \times \frac{(100 - 13)}{100} = 43.50 \text{ tons}$$

This same amount of dry substance must originally have been present in the pressed pulp entering the drums, since nothing but water is assumed to be removed in the drying process. The amount of pressed pulp is then

$$\frac{43.50 \times 100}{100 - 86} = 310.71 \text{ tons}$$

The amount of water evaporated is then

$$310.71 - 50.00 = 260.71 \text{ tons.}$$

(6) A factory produces 65 tons of dried pulp per day containing 12 per cent moisture; the pressed pulp contains 85 per cent

moisture. How many tons of water are evaporated per day? If 1 ton of coal evaporates 5.5 tons of water, how many tons of coal per day are required?

(7) If, in example (6), the moisture content of the pressed pulp is reduced to 84 instead of 85 per cent, what is the saving in tons of water evaporated per day, and in tons of coal for a 100-day campaign?

(8) Assume that it is desired to produce dried pulp of 12 per cent moisture content, and that anything below this represents needless evaporation. If in example (6) the moisture had been reduced to 10 instead of 12 per cent, how many tons of water per day would have been needlessly evaporated, and how many tons of coal would be wasted in a 100-day campaign?

Percentage of Molasses in Molasses Pulp.—The following formula will give the percentage of molasses in dried molasses pulp, which is calculated from the weights and moisture content of the molasses added and the molasses pulp sacked.

Let A = tons of dried molasses pulp sacked.
B = % moisture in molasses pulp sacked
C = tons of molasses used
D = % dry substance in molasses (Note:—If D is not known, it may be taken as approximately 80)
M = % molasses in molasses pulp

$$\text{Then } M = \frac{100\ C\ D}{A\ (100 - B)}$$

(9) A dryer produces in a day 70 tons of dried molasses pulp containing 11.5 per cent moisture and uses 18 tons of molasses containing 80 per cent dry substance. What percentage of molasses does the molasses pulp contain? How many tons of molasses would be required if it were desired to produce molasses pulp containing 30 per cent molasses?

APPENDIX

APPENDIX

TABLE 1

PROPERTIES OF STEAM

Steam Table British System

(Taken from Supplee's Mechanical Engineer's Reference Book, Third Edition, pages 625, 626 and 627. Courtesy of J. B. Lippincott Publishing Co.)

Press ob. at lbs. pr. sq. in.	Absolute pressure lbs. pr. sq. in.	Temp. Fahr. Scale	Units of Heat From 32° to T° Total pr. pound	Latent pr. pound	Bulk cub. ft. pr. lb.	Weight lbs. pr. cub. ft.
P	P	T	H	L	C	W
— 14	1	101.36	1112.8	1043.4	288.24	.00347
— 13	2	126.21	1120.4	1026.0	165.94	.00602
— 12	3	141.67	1125.1	1015.2	116.75	.00856
— 11	4	153.27	1128.7	1007.1	89.895	.01112
— 10	5	162.51	1131.5	1000.6	73.180	.01366
— 9	6	170.25	1133.8	995.17	61.742	.01619
— 8	7	176.97	1135.9	990.44	53.388	.01872
— 7	8	182.96	1137.7	986.22	47.046	.02125
— 6	9	188.36	1139.4	982.41	42.059	.02377
— 5	10	193.20	1140.8	978.99	38.037	.02628
— 4	11	197.60	1142.2	975.88	34.723	.02880
— 3	12	201.90	1143.5	972.84	31.945	.03130
— 2	13	205.77	1144.7	970.11	29.584	.03380
— 1	14	209.55	1145.8	967.43	27.551	.03629
0	14.7	212.00	1146.6	965.70	26.311	.03800
+ 5	20	227.95	1151.4	954.38	19.550	.05119
+ 10	25	240.07	1155.1	945.76	15.776	.06338
+ 15	30	250.26	1158.2	938.50	13.245	.07550
+ 20	35	259.22	1161.0	932.10	11.429	.08749
+ 25	40	267.17	1163.4	926.42	10.064	.09936
+ 30	45	274.33	1165.6	921.29	9.0002	.11111
+ 35	50	280.89	1167.6	916.58	8.1472	.12273
+ 40	55	286.96	1169.4	912.22	7.4468	.13428
+ 45	60	292.58	1171.2	908.18	6.8654	.14566
+ 50	65	297.84	1172.8	904.39	6.3715	.15694
+ 55	70	302.77	1174.3	900.84	5.9478	.16812
+ 60	75	307.42	1175.8	897.57	5.5805	.17919
+ 65	80	311.86	1177.0	894.27	5.2588	.19015

TABLE 1—CONTINUED

PROPERTIES OF STEAM

Steam Table British System

(Taken from Supplee's Mechanical Engineer's Reference Book, Third Edition, pages 625, 626 and 627. Courtesy of J. B. Lippincott Publishing Co.)

Press ob. at lbs. pr. sq. in.	Absolute pressure lbs. per sq. in.	Temp. Fahr. Scale	Units of Heat From 32° to T° Total pr. pound	Latent pr. pound	Bulk cub. ft. pr. lb.	Weight lbs. pr. cub. ft.
P	P	T	H	L	C	W
+ 70	85	316.08	1178.3	891.22	4.9748	.20101
+ 75	90	320.10	1179.6	888.31	4.7222	.21185
+ 80	95	323.94	1180.7	885.53	4.4961	.22241
+ 85	100	327.63	1181.9	882.85	4.2926	.23296
+ 90	105	331.18	1182.9	880.27	4.1083	.24340
+ 95	110	334.59	1183.9	877.80	3.9408	.25375
+ 100	115	337.89	1185.0	875.40	3.7878	.26400
+ 105	120	341.0	1185.9	873.09	3.6475	.27421
+ 110	125	344.1	1186.9	870.85	3.5184	.28422
+ 115	130	347.1	1187.8	868.68	3.3991	.29419
+ 120	135	350.0	1188.7	866.56	3.2880	.30406
+ 125	140	352.8	1189.5	864.49	3.1862	.31385
+ 130	145	355.6	1190.4	862.48	3.0908	.32354
+ 135	150	358.4	1191.2	860.45	3.0001	.33315
+ 140	155	361.6	1191.8	858.4	2.8958	.3466
+ 145	160	364.5	1192.5	856.5	2.7916	.3601
+ 150	165	367.3	1193.6	854.0	2.6873	.3736
+ 155	170	369.8	1194.7	852.5	2.5831	.3871
+ 160	175	372.0	1195.4	851.0	2.5171	.3973
+ 165	180	374.2	1196.1	849.4	2.4541	.4075
+ 175	190	378.5	1197.4	846.2	2.3299	.4292
+ 185	200	382.6	1198.7	843.3	2.2137	.4517
+ 195	210	386.6	1199.8	840.3	2.1192	.4719
+ 205	220	390.4	1201.0	837.5	2.0265	.4935
+ 215	230	394.0	1202.2	835.0	1.9360	.5165
+ 225	240	397.6	1203.2	832.3	1.8646	.5364
+ 235	250	401.0	1204.2	829.8	1.7874	.5595

Note—1 pound vacuum is equivalent to 2.03 inches of mercury.

TABLE 2

PERCENTAGE OF AVAILABLE GRANULATED ON DRY SUBSTANCE OF SUGAR SOLUTIONS MOLASSES PURITY OF 60

Purity	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Purity
60	0.0	.25	.5	.75	1.0	1.25	1.5	1.75	2.0	2.25	60
61	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	61
62	5.0	5.25	5.5	5.75	6.0	6.25	6.5	6.75	7.0	7.25	62
63	7.5	7.75	8.0	8.25	8.5	8.75	9.0	9.25	9.5	9.75	63
64	10.0	10.25	10.5	10.75	11.0	11.25	11.5	11.75	12.0	12.25	64
65	12.5	12.75	13.0	13.25	13.5	13.75	14.0	14.25	14.5	14.75	65
66	15.0	15.25	15.5	15.75	16.0	16.25	16.5	16.75	17.0	17.25	66
67	17.5	17.75	18.0	18.25	18.5	18.75	19.0	19.25	19.5	19.75	67
68	20.0	20.25	20.5	20.75	21.0	21.25	21.5	21.75	22.0	22.25	68
69	22.5	22.75	23.0	23.25	23.5	23.75	24.0	24.25	24.5	24.75	69
70	25.0	25.25	25.5	25.75	26.0	26.25	26.5	25.75	27.0	27.25*	70
71	27.5	27.75	28.0	28.25	28.5	28.75	29.0	29.25	29.5	29.75	71
72	30.0	30.25	30.5	30.75	31.0	31.25	31.5	31.75	32.0	32.25	72
73	32.5	32.75	33.0	33.25	33.5	33.75	34.0	34.25	34.5	34.75	73
74	35.0	35.25	35.5	35.75	36.0	36.25	36.5	36.75	37.0	37.25	74
75	37.5	37.75	38.0	38.25	38.5	38.75	39.0	39.25	39.5	39.75	75
76	40.0	40.25	40.5	40.75	41.0	41.25	41.5	41.75	42.0	42.25	76
77	42.5	42.75	43.0	43.25	43.5	43.75	44.0	44.25	44.5	44.75	77
78	45.0	45.25	45.5	45.75	46.0	46.25	46.5	46.75	47.0	47.25	78
79	47.5	47.75	48.0	48.25	48.5	48.75	49.0	49.25	49.5	49.75	79
80	50.0	50.25	50.5	50.75	51.0	51.25	51.5	51.75	52.0	52.25	80
81	52.5	52.75	53.0	53.25	53.5	53.75	54.0	54.25	54.5	54.75	81
82	55.0	55.25	55.5	55.75	56.0	56.25	56.5	56.75	57.0	57.25	82
83	57.5	57.75	58.0	58.25	58.5	57.75	59.0	59.25	59.5	59.75	83
84	60.0	60.25	60.5	60.75	61.0	61.25	61.5	61.75	62.0	62.25	84
85	62.5	62.75	63.0	63.25	63.5	63.75	64.0	64.25	64.5	64.75	85
86	65.0	65.25	65.5	65.75	66.0	66.25	66.5	66.75	67.0	67.75	86
87	67.5	67.75	68.0	68.25	68.5	68.75	69.0	69.25	69.5	69.75	87
88	70.0	70.25	70.5	75.75	71.0	71.25	71.5	71.75	72.0	72.25	88
89	72.5	72.75	73.0	73.25	73.5	73.75	74.0	74.25	74.5	74.75	89
90	75.0	75.25	75.5	75.75	76.0	76.25	76.5	76.75	11.0	11.25	90
91	77.5	77.75	78.0	78.25	78.5	78.75	79.0	79.25	79.5	79.75	91
92	80.0	80.25	80.5	80.75	81.0	81.25	81.5	81.75	82.0	72.25	92
93	82.5	82.75	83.0	83.25	83.5	83.75	84.0	84.25	84.5	84.75	93
94	85.0	85.25	85.5	85.75	86.0	86.25	86.5	86.75	87.0	87.25	94
95	87.5	87.75	88.0	88.25	88.5	88.75	89.0	89.25	89.5	89.75	95
96	90.0	90.25	90.5	90.75	91.0	91.25	91.5	91.75	92.0	92.25	96
97	92.5	92.75	93.0	93.25	93.5	93.75	94.0	94.25	94.5	94.75	97
98	95.0	95.25	95.5	95.75	96.0	96.25	96.5	96.75	97.0	97.25	98
99	97.5	97.75	98.0	98.25	98.5	98.75	99.0	99.25	99.5	99.75	99
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

DERIVATION:—If P = purity and F = granulated factor, F = 2.5 (P — 60).

TABLE 3

PERCENTAGE OF AVAILABLE GRANULATED ON TOTAL SUGAR OF SUGAR SOLUTIONS MOLASSES PURITY OF 60

This table should not be confused with Table 2, which is the one mostly employed in taking stock. Table 3 is intended for use where the polarization and purity of a product are known. E. g., if a lot of 10,000 lbs. of raw sugar has a polarization of 96.7 and a purity of 97.1, the amount of sugar in the raw sugar is 10,000 × 96.7 ÷ 100 = 9,670 lbs. The factor corresponding to 97.1 in Table 3 is 95.52. The "available granulated" is then 9,670 × 95.52 ÷ 100 = 9,237 lbs.

Purity	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Purity
60	0.00	0.42	0.83	1.25	1.66	2.07	2.48	2.88	3.29	3.69	60
61	4.10	4.50	4.90	5.30	5.70	6.10	6.49	6.89	7.28	7.67	61
62	8.06	8.45	8.84	9.23	9.62	10.00	10.38	10.77	11.15	11.53	62
63	11.90	12.28	12.66	13.03	13.41	13.78	14.15	14.52	14.89	15.26	63
64	15.62	15.99	16.36	16.72	17.08	17.44	17.80	18.16	18.52	18.88	64
65	19.23	19.59	19.94	20.29	20.64	20.99	21.34	21.69	22.04	22.38	65
66	22.73	23.07	23.41	23.76	24.10	24.44	24.77	25.11	25.45	25.79	66
67	26.12	26.45	26.79	27.12	27.45	27.78	28.11	28.43	28.76	29.09	67
68	29.41	29.74	30.06	30.38	30.70	31.02	31.34	31.66	31.98	32.29	68
69	32.61	32.92	33.24	33.55	33.86	34.17	34.48	34.79	35.10	35.41	69
70	35.71	36.02	36.32	36.63	36.93	37.23	37.54	37.84	38.14	38.43	70
71	38.73	39.03	39.33	39.62	39.92	40.21	40.50	40.79	41.09	41.38	71
72	41.67	41.96	42.24	42.53	42.82	43.10	43.39	43.67	43.96	44.24	72
73	44.52	44.80	45.08	45.36	45.64	45.92	46.20	46.47	46.75	47.02	73
74	47.30	47.57	47.84	48.12	48.39	48.66	48.93	49.20	49.47	49.73	74
75	50.00	50.27	50.53	50.80	51.06	51.32	51.59	51.85	52.11	52.37	75
76	52.63	52.89	53.15	53.41	53.66	53.92	54.18	54.43	54.69	54.94	76
77	55.19	55.45	55.70	55.95	56.20	56.45	56.70	56.95	57.20	57.45	77
78	57.69	57.94	58.18	58.43	58.67	58.92	59.16	59.40	59.64	59.89	78
79	60.13	60.37	60.61	60.85	61.08	61.32	61.56	61.79	62.03	62.27	79
80	62.50	62.73	62.97	63.20	63.43	63.66	63.90	64.13	64.36	64.59	80
81	64.81	65.04	65.27	65.50	65.72	65.95	66.18	66.40	66.63	66.85	81
82	67.07	67.30	67.52	67.74	67.96	68.18	68.40	68.62	68.84	69.06	82
83	69.28	69.49	69.71	69.93	70.14	70.36	70.57	70.79	71.00	71.22	83
84	71.43	71.64	71.85	72.06	72.27	72.49	72.70	72.90	73.11	73.32	84
85	73.53	73.74	73.94	74.15	74.36	74.56	74.77	74.97	75.17	75.38	85
86	75.58	75.78	75.99	76.19	76.39	76.59	76.79	76.99	77.19	77.39	86
87	77.59	77.78	77.98	78.18	78.38	78.57	78.77	78.96	79.16	79.35	87
88	79.55	79.74	79.93	80.12	80.32	80.51	80.70	80.89	81.08	81.27	88
89	81.46	81.65	81.84	82.03	82.21	82.40	82.59	82.78	82.96	83.15	89
90	83.33	83.52	83.70	83.89	84.07	84.25	84.44	84.62	84.80	84.98	90
91	85.16	85.35	85.53	85.71	85.89	86.07	86.24	86.42	86.60	86.78	91
92	86.96	87.13	87.31	87.49	87.66	87.84	88.01	88.19	88.36	88.54	92
93	88.71	88.88	89.06	89.23	89.40	89.57	89.74	89.91	90.09	90.26	93
94	90.43	90.60	90.76	90.93	91.10	91.27	91.44	91.61	91.77	91.94	94
95	92.11	92.27	92.44	92.60	92.77	92.93	93.10	93.26	93.42	93.59	95
96	93.75	93.91	94.07	94.24	94.40	94.56	94.72	94.88	95.04	95.20	96
97	95.36	95.52	95.68	95.84	96.00	96.15	96.31	96.47	96.63	96.78	97
98	96.94	97.09	97.25	97.41	97.56	97.72	97.87	98.02	98.18	98.33	98
99	98.48	98.64	98.79	98.94	99.09	99.25	99.40	99.55	99.70	99.85	99
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

DERIVATION:—If P = purity and F^1 = granulated factor, $F^1 = \frac{250\ (P - 60)}{P}$

TABLE 4

BRIX, BAUME, AND SPECIFIC GRAVITY OF SUGAR SOLUTIONS

Table showing equivalent degrees Brix, degrees Baume, specific gravity at 20/20° C., pounds per cubic foot, and pounds of dry substance per cubic foot, from *values of the U. S. Bureau of Standards.

EXPLANATION

The Baume scale is based on a modulus of 145 and is derived from specific gravities at 20/20° C. (Bureau of Standards Baume scale for sugar solutions.) That is, if d = degrees Baume and s = specific gravity at 20/20° C.

$$\text{Then } d = 145 - \frac{145}{s}$$

The values for specific gravity at 20/20° C. represent true specific gravity, i. e., the ratio of the weights in vacuo of equal volumes of the sugar solution and of water, based on the determinations of Plato.

The values for "pounds per cubic foot" represent weights at 20° C. in air against brass weights.

The values for "pounds of dry substance per cubic foot" are calculated by multiplying the "pounds per cubic foot" by the percentage of dry substance represented by the "degrees Brix". For impure sugar solutions these values are only approximate.

Degrees Brix or % Sugar by Wt.	Degrees Baume modulus 145	Specific Gravity at 20/20° C.	Pounds per Cubic Foot	Pounds Dry Sub. per Cu. Ft.	Degrees Brix or % Sugar by Wt.	Degrees Baume modulus 145	Specific Gravity at 20/20° C.	Pounds per Cubic Foot	Pounds Dry Sub. per Cu. Ft.
0.0	0.00	1.00000	62.25	0.00	12.5	6.96	1.05041	65.39	8.17
0.5	0.28	1.00194	62.37	0.31	13.0	7.24	1.05252	65.52	8.52
1.0	0.56	1.00389	62.49	0.62	13.5	7.51	1.05464	65.65	8.86
1.5	0.84	1.00584	62.61	0.94	14.0	7.79	1.05677	65.79	9.21
2.0	1.12	1.00779	62.73	1.25	14.5	8.07	1.05890	65.92	9.56
2.5	1.40	1.00976	62.86	1.57	15.0	8.34	1.06104	66.05	9.91
3.0	1.68	1.01172	62.98	1.89	15.5	8.62	1.06319	66.19	10.26
3.5	1.96	1.01369	63.10	2.21	16.0	8.89	1.06534	66.32	10.61
4.0	2.24	1.01567	63.23	2.53	16.5	9.17	1.06751	66.46	10.97
4.5	2.52	1.01766	63.36	2.85	17.0	9.45	1.06968	66.59	11.32
5.0	2.79	1.01965	63.47	3.17	17.5	9.72	1.07186	66.73	11.68
5.5	3.07	1.02165	63.60	3.50	18.0	10.00	1.07404	66.86	12.03
6.0	3.35	1.02366	63.72	3.82	18.5	10.27	1.07624	67.00	12.40
6.5	3.63	1.02568	63.85	4.15	19.0	10.55	1.07844	67.14	12.76
7.0	3.91	1.02770	63.97	4.47	19.5	10.82	1.08065	67.28	13.12
7.5	4.19	1.02973	64.10	4.80	20.0	11.10	1.08287	67.41	13.48
8.0	4.46	1.03176	64.23	5.14	20.5	11.37	1.08510	67.55	13.85
8.5	4.74	1.03381	64.36	5.47	21.0	11.65	1.08733	67.69	14.21
9.0	5.02	1.03586	64.48	5.80	21.5	11.92	1.08958	67.83	14.58
9.5	5.30	1.03792	64.61	6.14	22.0	12.20	1.09183	67.97	14.95
10.0	5.57	1.03998	64.74	6.47	22.5	12.47	1.09409	68.11	15.32
10.5	5.85	1.04205	64.87	6.81	23.0	12.74	1.09636	68.26	15.70
11.0	6.13	1.04413	65.00	7.15	23.5	13.02	1.09863	68.40	16.07
11.5	6.41	1.04622	65.13	7.49	24.0	13.29	1.10092	68.54	16.45
12.0	6.68	1.04831	65.26	7.83	24.5	13.57	1.10321	68.69	16.83

TABLE 4—CONTINUED

Degrees Brix or % Sugar by Wt.	Degrees Baume modulus 145	Specific Gravity at 20/20° C.	Pounds per Cubic Foot	Pounds Dry Sub. per Cu. Ft.	Degrees Brix or % Sugar by Wt.	Degrees Baume modulus 145	Specific Gravity at 20/20° C.	Pounds per Cubic Foot	Pounds Dry Sub. per Cu. Ft.
25.0	13.84	1.10551	68.82	17.21	52.0	28.33	1.24284	77.38	40.24
25.5	14.11	1.10782	68.97	17.59	52.5	28.59	1.24563	77.56	40.72
26.0	14.39	1.11014	69.11	17.97	53.0	28.86	1.24844	77.73	41.20
26.5	14.66	1.11246	69.26	18.35	53.5	29.12	1.25126	77.91	41.68
27.0	14.93	1.11480	69.40	18.74	54.0	29.38	1.25408	78.08	42.16
27.5	15.20	1.11714	69.55	19.13	54.5	29.64	1.25692	78.26	42.65
28.0	15.48	1.11949	69.70	19.52	55.0	29.90	1.25976	78.44	43.14
28.5	15.75	1.12185	69.84	19.90	55.5	30.16	1.26261	78.61	43.63
29.0	16.02	1.12422	69.99	20.30	56.0	30.42	1.26548	78.79	44.12
29.5	16.29	1.12659	70.14	20.69	56.5	30.68	1.26835	78.97	44.62
30.0	16.57	1.12898	70.29	21.08	57.0	30.94	1.27123	79.15	45.11
30.5	16.84	1.13137	70.44	21.48	57.5	31.20	1.27413	79.33	45.61
31.0	17.11	1.13378	70.59	21.88	58.0	31.46	1.27703	79.51	46.12
31.5	17.38	1.13619	70.74	22.28	58.5	31.71	1.27994	79.69	46.62
32.0	17.65	1.13861	70.89	22.68	59.0	31.97	1.28286	79.88	47.13
32.5	17.92	1.14103	71.04	23.09	59.5	32.23	1.28579	80.06	47.64
33.0	18.19	1.14347	71.19	23.49	60.0	32.49	1.28873	80.24	48.14
33.5	18.46	1.14592	71.34	23.90	60.5	32.74	1.29168	80.43	48.66
34.0	18.73	1.14837	71.50	24.31	61.0	33.00	1.29464	80.61	49.17
34.5	19.00	1.15084	71.65	24.72	61.5	33.26	1.29761	80.79	49.69
35.0	19.28	1.15331	71.80	25.13	62.0	33.51	1.30059	80.98	50.21
35.5	19.55	1.15579	71.96	25.55	62.5	33.77	1.30358	81.16	50.73
36.0	19.81	1.15828	72.11	25.96	63.0	34.02	1.30657	81.35	51.25
36.5	20.08	1.16078	72.27	26.38	63.5	34.28	1.30958	81.54	51.78
37.0	20.35	1.16329	72.42	26.80	64.0	34.53	1.31260	81.73	52.31
37.5	20.62	1.16581	72.58	27.22	64.5	34.79	1.31563	81.92	52.84
38.0	20.89	1.16833	72.74	27.64	65.0	35.04	1.31866	82.11	53.37
38.5	21.16	1.17087	72.90	28.07	65.5	35.29	1.32171	82.30	53.91
39.0	21.43	1.17341	73.06	28.49	66.0	35.55	1.32476	82.49	54.44
39.5	21.70	1.17596	73.21	28.92	66.5	35.80	1.32783	82.68	54.98
40.0	21.97	1.17853	73.37	29.35	67.0	36.05	1.33090	82.87	55.52
40.5	22.23	1.18110	73.53	29.78	67.5	36.30	1.33399	83.06	56.07
41.0	22.50	1.18368	73.70	30.22	68.0	36.55	1.33708	83.25	56.61
41.5	22.77	1.18627	73.86	30.65	68.5	36.81	1.34019	83.45	57.16
42.0	23.04	1.18887	74.02	31.09	69.0	37.06	1.34330	83.64	57.71
42.5	23.30	1.19148	74.18	31.53	69.5	37.31	1.34642	83.84	58.27
43.0	23.57	1.19410	74.34	31.97	70.0	37.56	1.34956	84.03	58.82
43.5	23.84	1.19673	74.51	32.41	70.5	37.81	1.35270	84.23	59.38
44.0	24.10	1.19936	74.67	32.86	71.0	38.06	1.35585	84.42	59.94
44.5	24.37	1.20201	74.84	33.30	71.5	38.30	1.35901	84.62	60.50
45.0	24.63	1.20467	75.00	33.75	72.0	38.55	1.36218	84.82	61.07
45.5	24.90	1.20733	75.17	34.20	72.5	38.80	1.36536	85.02	61.64
46.0	25.17	1.21001	75.33	34.65	73.0	39.05	1.36856	85.22	62.21
46.5	25.43	1.21269	75.50	35.11	73.5	39.30	1.37176	85.42	62.78
47.0	25.70	1.21538	75.67	35.56	74.0	39.54	1.37496	85.61	63.35
47.5	25.96	1.21809	75.84	36.02	74.5	39.79	1.37818	85.82	63.94
48.0	26.23	1.22080	76.01	36.48	75.0	40.03	1.38141	86.02	64.52
48.5	26.49	1.22352	76.18	36.95	75.5	40.28	1.38465	86.22	65.10
49.0	26.75	1.22625	76.35	37.41	76.0	40.53	1.38790	86.42	65.68
49.5	27.02	1.22899	76.52	37.87	76.5	40.77	1.39115	86.62	66.26
50.0	27.28	1.23174	76.69	38.35	77.0	41.01	1.39442	86.83	66.86
50.5	27.54	1.23450	76.86	38.81	77.5	41.26	1.39769	87.03	67.45
51.0	27.81	1.23727	77.03	39.29	78.0	41.50	1.40098	87.24	68.05
51.5	28.07	1.24005	77.21	39.76	78.5	41.74	1.40427	87.44	68.64

TABLE 4—CONTINUED

Degrees Brix or % Sugar by Wt.	Degrees Baume modulus 145	Specific Gravity at 20/20° C.	Pounds per Cubic Foot	Pounds Dry Sub. per Cu. Ft.	Degrees Brix or % Sugar by Wt.	Degrees Baume modulus 145	Specific Gravity at 20/20° C.	Pounds per Cubic Foot	Pounds Dry Sub. per Cu. Ft.
79.0	41.99	1.40758	87.65	69.24	89.5	46.97	1.47909	92.10	82.43
79.5	42.23	1.41089	87.85	69.84	90.0	47.20	1.48259	92.32	83.09
80.0	42.47	1.41421	88.06	70.45	90.5	47.43	1.48611	92.54	83.74
80.5	42.71	1.41754	88.27	71.06	91.0	47.66	1.48963	92.76	84.41
81.0	42.95	1.42088	88.48	71.67	91.5	47.89	1.49316	92.98	85.09
81.5	43.19	1.42423	88.68	72.27	92.0	48.12	1.49671	93.20	85.74
82.0	43.43	1.42759	88.89	72.89	92.5	48.35	1.50026	93.42	86.41
82.5	43.67	1.43096	89.10	73.51	93.0	48.58	1.50381	93.64	87.09
83.0	43.91	1.43434	89.31	74.13	93.5	48.81	1.50738	93.87	87.77
83.5	44.15	1.43773	89.53	74.76	94.0	49.03	1.51096	94.09	88.44
84.0	44.38	1.44112	89.74	75.38	94.5	49.26	1.51454	94.31	89.12
84.5	44.62	1.44453	89.95	76.01	95.0	49.49	1.51814	94.54	89.81
85.0	44.86	1.44794	90.16	76.64	95.5	49.71	1.52174	94.76	90.50
85.5	45.09	1.45137	90.38	77.27	96.0	49.94	1.52535	94.99	91.19
86.0	45.33	1.45480	90.59	77.91	96.5	50.16	1.52897	95.21	91.88
86.5	45.57	1.45824	90.80	78.54	97.0	50.39	1.53260	95.44	92.57
87.0	45.80	1.46170	91.02	79.19	97.5	50.61	1.53623	95.66	93.27
87.5	46.03	1.46516	91.24	79.84	98.0	50.84	1.53988	95.89	93.97
88.0	46.27	1.46862	91.45	80.48	98.5	51.06	1.54353	96.12	94.68
88.5	46.50	1.47210	91.67	81.13	99.0	51.28	1.54719	96.35	95.39
89.0	46.73	1.47559	91.89	81.78	99.5	51.50	1.55087	96.58	96.10
					100.0	51.23	1.55454	96.80	96.80

*Circulars 19 and 44.

TABLE No. 5

SPECIFIC GRAVITY OF VARIOUS MATERIALS

	Weight In Pounds of One Cubic Foot
Beets	40-42
Beet pulp, fresh	37-40
Beet pulp, fermented	40-50
Coal (Colorado lignite)	50-52
Coke	27
Lime, burned	50-60
Limestone	90
Molasses	90
Sugar, raw	50-55
Sugar, white	55
	Sp. Gr. True
Sugar	1.591
Lime, burned	2.30-4.20
Limestone, usually	2.65-2.70

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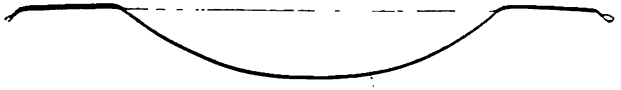

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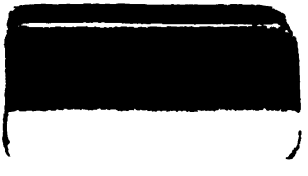
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